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THESIS

RDT&E LABORATORY CAPACITY UTILIZATION AND PRODUCTIVITY MEASUREMENT METHODS FOR FINANCIAL DECISION-MAKING WITHIN DON

by

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June 1998

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This thesis identifies capacity utilization and productivity measures applicable to Department of the Navy (DON) Research, Development, Test and Evaluation (RDT&E) laboratories. The recent emphasis on efficiency and sound business practices from a financial management perspective mandates that the Navy evaluate and incorporate appropriate laboratory performance measures. Industry capacity utilization and productivity measurement techniques and models were evaluated for their potential application to the Naval Air Warfare Center Aircraft Division (NAWCAD) RDT&E organization. The CAM-I capacity model was selected from the twelve industry models reviewed as a measure of capacity utilization. Additionally, laboratory productivity was examined in terms of revenue and full cost with measures of return on operations, operating margin, and operating margin per square foot. Productivity data were collected from NAWCAD accounting records. Observations, interviews, and a questionnaire were used to gather laboratory operating characteristics and capacity utilization data. The data were input to the selected measures and the results were analyzed. This analysis found that the measures identified provide a financial basis for responsible RDT&E resource decision-making and have potential application to all Department of Defense (DOD) RDT&E laboratory activities.

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RDT&E LABORATORY CAPACITY UTILIZATION AND PRODUCTIVITY MEASUREMENT METHODS FOR FINANCIAL DECISION-MAKING WITHIN DON

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ABSTRACT

This thesis identifies capacity utilization and productivity measures applicable to Department of the Navy (DON) Research, Development, Test and Evaluation (RDT&E) laboratories. The recent emphasis on efficiency and sound business practices from a financial management perspective mandates that the Navy evaluate and incorporate appropriate laboratory performance measures. Industry capacity utilization and productivity measurement techniques and models were evaluated for their potential application to the Naval Air Warfare Center Aircraft Division (NAWCAD) RDT&E organization. The CAM-I capacity model was selected from the twelve industry models reviewed as a measure of capacity utilization. Additionally, laboratory productivity was examined in terms of revenue and full cost with measures of return on operations, operating margin, and operating margin per square foot. Productivity data were collected from NAWCAD accounting records. Observations, interviews, and a questionnaire were used to gather laboratory operating characteristics and capacity utilization data. The data were input to the selected measures and the results were analyzed. This analysis found that the measures identified provide a financial basis for responsible RDT&E resource decision-making and have potential application to all Department of Defense (DOD) RDT&E laboratory activities.

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I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DOD) has experienced a decade of budget reductions and downsizing initiatives with additional cuts projected for the future. Increased competition for shrinking budget dollars and financial challenges associated with downsizing compel DOD organizations to use scarce resource dollars more efficiently. Managers of defense activities are specifically challenged to improve utilization and productivity rates in order to ensure mission requirements will be met in an environment of reduced resource availability.

The recent trend of downsizing and reduced budgets has had a significant impact on Research, Development, Test and Evaluation (RDT&E) activities within the Department of the Navy (DoN). Functional realignment, consolidation, and reorganization of Navy RDT&E activities have been implemented in response to downsizing initiatives (Collier, 1998). There has also been a conscious shift away from traditional DOD resource allocation decision metrics towards performance measures and sound business practices used by industry in the private sector. Evidence of this new direction is found in the *Defense Reform Initiative, The Business Strategy for Defense for the 21st Century*, released November 10, 1997. In this document, William S. Cohen, United States Secretary of Defense, states:

> DOD has labored under support systems and business practices that are at least a generation out of step with modern corporate America. DOD support systems and practices that were once state-of-the-art are now antiquated compared with the systems and practices in place in the corporate world, while other systems were developed in their own defense-unique culture and have never corresponded with the best business practices of the private sector. This cannot and will not continue. (Cohen, 1997)

To further define best practices reform for DOD, a series of initiatives have been established in the following major areas:

- **Reengineering:** Adopt modern business practices to achieve world-class standards of performance.
- **Consolidation:** Streamline organizations to remove redundancy and maximize synergy.
- **Competition:** Apply market mechanisms to improve quality, reduce costs, and respond to customer needs.
- **Elimination:** Reduce excess support structures to free resources and focus on core competencies. (Cohen, 1997)

This new orientation represents a fundamental change in the way RDT&E activities evaluate resource allocation alternatives. As a result, requests for RDT&E budget dollars throughout the defense budgeting process will be reviewed with increased emphasis on sound business justification. These new requirements significantly impact DON RDT&E resource management practices. DON RDT&E resource managers do not presently have an adequate system for measuring capacity utilization and productivity of individual laboratories, as evidenced by the following statement from the Office of the Under Secretary of Defense, Acquisition and Technology:

> Efforts to improve the overall cost efficiency of Defense laboratories and test centers have been significantly limited by the pervasive absence of accurate, credible and comparable cost data. Current financial information available to RDT&E management is organized according to the budget and financial control process, a paradigm that emphasizes level of effort funding and "management to budget" instead of cost control. In addition, the limited cost data that are available for management review are not generally comparable across organizations due to the inconsistent financial methodologies and approaches used by the various activities and services. (Memorandum (i), 1997)

One of the issues discussed in the Defense Reform Initiative with regards to RDT&E infrastructure was that the performance and cost of laboratories and test and evaluation facilities "can be improved through a combination of improved management, internal restructuring, and increased inter-Service support". (Memorandum (ii), 1997) These improvements can be achieved with proper management of available resources, increased efficiency, and greater control of costs. Establishment of a Cost-Based Management Tool (CBMT) for Laboratories and Test and Evaluation Centers has been directed by the Deputy Secretary of Defense to provide executive level visibility of the full costs associated with laboratories and test and evaluation centers. The CBMT is structured so as to provide accurate and credible information suitable for identifying cost efficiencies and financial best practices across DOD. (Memorandum (i), 1997)

This executive level cost analysis tool, scheduled to be fully operational by the end of FY 1998, does not provide for cost and performance analysis at the individual laboratory level. DON RDT&E activities are organized by function and physically operate as separate laboratories. Each laboratory is designed to meet specific DOD and

DON requirements as part of the overall RDT&E mission. RDT&E managers, concerned with improving efficiency and resource allocation, need to develop new strategies to improve capacity utilization and productivity of individual laboratories. Proper performance measures used to evaluate laboratory capacity utilization and productivity, put into terms useful for financial analysis, will enable managers to have better decision-making information.

The funding and accounting processes for DON RDT&E activities have changed over the past few years, significantly impacting financial operating procedures. Financial information available to managers for decision-making under the new system is not providing the appropriate data necessary for evaluation of productivity and capacity utilization. The introduction of the Navy Working Capital Fund (NWCF) as the primary source of RDT&E funding has changed the way laboratories account for costs, revenues, and laboratory rate determination. This relatively new funding process, along with its associated accounting procedures, has contributed to the difficulty of accurate measurement of laboratory performance in financial terms.

The new emphasis on efficiency and sound business practices from a financial management perspective mandates that the Navy evaluate and incorporate appropriate performance measurement tools for RDT&E laboratories. Laboratory capacity utilization and productivity are primary indicators of performance. If these tools are integrated into the analysis process they will increase the quality of decision-making information available to the resource manager. This thesis will help identify appropriate laboratory

capacity utilization and productivity measures and analyze the potential cost benefit of their use.

B. OBJECTIVE

The primary objective of this thesis is to identify capacity utilization and productivity measures for RDT&E facilities to improve management of DON resources. In order to make informed business decisions on spending and resource allocation, Research and Engineering managers must have adequate information about the productivity and cost efficiency of individual RDT&E laboratories. The performance measurements identified were analyzed using data collected from NAWCAD RDT&E laboratories operational in FY 1997. The results were evaluated for their usefulness as a financial analysis and decision-making tool. These measures of laboratory capacity utilization and productivity should provide information necessary to improve the efficient use of DON RDT&E resources.

C. RESEARCH QUESTIONS

The following questions were addressed:

1. Primary:

How do we measure capacity utilization and productivity of DON RDT&E facilities in terms useful for financial and resource allocation decision making?

2. Secondary:

(1) What are the plausible methods of measuring capacity utilization and productivity for RDT&E facilities?

(2) Can existing production capacity models be applied to non-production environments such as research laboratories?

(3) Are there existing Research and Development benchmark performance measures in industry?

(4) Can similar measures be applied to DON RDT&E laboratory facilities?

(5) Can dissimilar laboratories be classified into categories useful for financial performance comparisons?

(6) Can a consensus approach to measuring capacity utilization and productivity be applicable to all RDT&E activities?

D. SCOPE OF THESIS

This thesis evaluates potential capacity utilization and productivity measurement techniques and models applicable to DON RDT&E facilities, incorporating adjustments necessary to accurately capture the unique characteristics of research and development laboratory activity. Measures were reviewed for their ability to provide quantitative analysis of laboratory financial performance. The measurement methods identified as appropriate were tested using data from a sample of NAWCAD RDT&E laboratories.

Results were evaluated for their potential to improve the quality of information available for RDT&E laboratory resource management and decision-making.

E. METHODOLOGY

The methodology used for this research was divided into the following steps: (1) review of the pertinent literature and existing models, (2) identification of laboratory classifications and categorization, (3) review of potential benchmark measures existing in industry, (4) determination of appropriate performance measurement models and techniques, (5) collection of data, (6) application of data in selected models, and (7) analysis of results.

(1) Literature: A review of the literature on existing models for capacity utilization and productivity was conducted. The findings were used to select the most appropriate performance measurement models and techniques applicable to the NAWCAD RDT&E laboratory environment.

(2) Classifications: Laboratory organizational structure, characteristics and classifications were identified to establish a useful baseline of comparison among the hundreds of different NAWCAD RDT&E laboratories.

(3) Industry Benchmark Review: A review was conducted to determine if existing industry R&D capacity utilization and productivity measurement techniques could be applied as NAWCAD RDT&E laboratory performance benchmarks.

(4) Model: Appropriate capacity utilization and productivity measures were selected. The models considered were reviewed for their ability to provide quantitative analysis of laboratory performance while meeting NAWCAD objectives for RDT&E laboratory capacity utilization and productivity management. Selection of the applicable measures and model was determined from a comparison of NAWCAD RDT&E laboratory management objectives to the different model attributes. A model was chosen that appeared to provide the closest fit for the unique RDT&E laboratory environment.

(5) Data: Data were collected from a sample of NAWCAD RDT&E laboratories. An existing database established for NAWCAD Aircrew Systems Level II Laboratories provided direct cost, revenue, and square footage data for the selected laboratories. Additional cost data were collected from NAWCAD accounting records. Interviews with the NAWCAD Comptroller, laboratory managers, and facility supervisors, were conducted, and a questionnaire was distributed to gather data about laboratory operating characteristics and equipment utilization.

(6) Model Application: The data were used in the selected model and results presented for analysis as measures of capacity utilization and productivity of RDT&E laboratories. The sample of data provide a baseline for laboratory performance measurement that may potentially apply to all classifications of DOD RDT&E laboratories.

(7) Analysis: Analysis of research results includes a review of the model results as presented with NAWCAD RDT&E laboratory data. The model was evaluated by the

author for its potential to improve the quality of laboratory performance information and analysis provided for RDT&E laboratory resource management and decision-making.

II. NAWCAD RDT&E LABORATORY ORGANIZATION

A. OVERVIEW OF NAWCAD RDT&E ORGANIZATION

The Naval Air Warfare Center Aircraft Division (NAWCAD) is a component of the Naval Air Systems Command (NAVAIRSYSCOM) headquartered in Patuxent River, Maryland. The primary mission of NAWCAD is to support research, development, test and evaluation (RDT&E), engineering and fleet support of Navy and Marine Corps air vehicle systems and trainers. The full spectrum of the RDT&E effort integrates a wide range of DOD activities and resources. The NAWCAD is the steward of the ranges, test facilities, laboratories, and aircraft necessary to support the Fleet's acquisition requirements (Dyer, 1997). This thesis focuses on the laboratory facilities and resources located at Naval Air Station (NAS) Patuxent River, Maryland, which perform research and development in support of the NAWCAD RDT&E mission. Understanding the characteristics of NAWCAD RDT&E laboratory operations and activities is the first step towards designing laboratory performance measures useful for business decision-making.

1. NAWCAD Laboratory Facilities and Equipment

There are over five hundred laboratories operated by NAWCAD.[1] These laboratories are physically housed in two primary buildings designed to accommodate the unique structural and environmental requirements of an RDT&E activity. Each laboratory utilizes facilities and equipment allocated to meet its functional requirements. The specific space allocated to each laboratory can be categorized into one of three types of space designs: (1) High Bay Mechanical, (2) Raised floor computer spaces, and (3) General purpose clean spaces (Harris, 1998). A description of each is provided below:

- *High Bay Mechanical* – Large square footage space with two story high ceiling to accommodate large equipment and test requirements
- *Raised floor computer spaces* – Environmentally controlled space with additional electrical access for computer and computer related equipment
- *General purpose clean space* – standard electrical and environmental design with minimal specialized equipment design requirements

Many different types of equipment, from large mechanical devices to small technical measurement tools, are owned and operated by NAWCAD RDT&E laboratories. They are the tools that scientists and technicians use to perform required laboratory RDT&E activities. Each laboratory houses specific types of equipment designed to meet its functional requirements. The equipment types include unique,

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[1] DOD defines laboratory as an activity (an aggregate of personnel and facilities located at one base, under the same command) owned and operated by a DOD component, that performs predominantly science and technology, engineering development, systems engineering, engineering support of deployed material and its modernization, and/or in-service engineering work (GAO, 1998).

highly specialized items such as an ejection seat tower that simulates the actual aircraft ejection environment, as well as common, universal use items such as computers and video recording devices. The laboratories are configured to accommodate their respective equipment requirements, which can be categorized into one of the following general descriptions:

- *Large mechanical devices* – (equipment/test items with space/utility requirements greater than single floor space designs) e.g. horizontal accelerator equipment which requires over 300 ft of sub-floor level architecture for rail/track design.

- *Specialized technical workbench areas* - (work areas designed for tasks utilizing specialized equipment or technology) e.g. electronic test benches, simulation and modeling computers, video analysis equipment.

- *Non-Technical workbench areas* - (variable use work areas designed for a variety of tasks, not restricted to specific equipment or technology) e.g. open laboratory benches for general material and equipment handling, parts and inventory.

Daily laboratory activity consists of scientists and technicians utilizing the necessary equipment and facilities to perform RDT&E tasks. This connection between laboratory activity and equipment utilization could provide an indication of capacity utilization for individual laboratories. However, there is no standard format established to account for equipment use under the present system.

2. NAWCAD Laboratory Competencies

The laboratories are administratively grouped into "competencies". Each competency represents a group of laboratories designed to support similar mission

requirements. The competency designations separate the RDT&E laboratories into two primary areas: (1) Research and Engineering, and (2) Test and Evaluation. The facilities primarily supporting Research and Engineering are labeled 4.0 competency laboratories, and the facilities primarily supporting Test and Evaluation are labeled 5.0 competency laboratories. Although some work is shared between competencies, the laboratories operate independently and report to their own competency managers. Of the 500 RDT&E laboratories, 350 are identified with the Research and Engineering (4.0) competency. The data for this thesis were collected from a subset of the Research and Engineering (4.0) competency laboratories. The operating characteristics of these laboratories are described in the following section.

B. NAWCAD RESEARCH AND ENGENEERING (4.0) COMPENTENCY LABORATORIES

The primary function of Research and Engineering (4.0) competency laboratories is to provide basic research, applied research, troubleshooting, and engineering support for DOD mission requirements.[2] (Collier, 1998) Other Research and Engineering (4.0) laboratory functions include troubleshooting, engineering, and life cycle support for existing fleet assets.

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[2] DOD defines basic research as efforts typically performed in laboratories as experiments to explore the basic laws of science and their potential application to DOD weapon systems or technology development. Applied research is research concerned with the practical application of knowledge, material, and/or techniques directed toward a solution to an existent or anticipated military requirement. (GAO, 1998, p. 87)

1. Research and Engineering (4.0) Laboratory Activity

The laboratories employ a variety of scientists and technicians with expertise in specific areas needed to support the laboratory functions. Each individual laboratory may perform any or all of the functions previously described. The unique capabilities of each laboratory are utilized to meet specific RDT&E project and mission requirements. The types of laboratory activities involved in meeting these requirements vary depending on the specific project requirements for a laboratory at a specific point in time. Based on interviews with laboratory managers (Collier and Harris, 1998) and observation of Research and Engineering (4.0) laboratory activity, the following common types of activities were identified:

- *Research and Development activity* – Laboratory conducts basic and applied research, tasks are generally not well defined, nor repetitive.

- *Certification activity* – Laboratory is required to validate an aircraft system prior to flight, flight clearance, or fleet use.

- *In-Service Support activity* – Laboratory is used primarily to provide direct fleet support, such as troubleshooting and correcting existing hardware and software problems reported by the fleet.

- *Production activity* – Laboratory activity consists of repetitive, defined tasks.

- *Software Support activity* – Laboratory provides programming and ADP support.

Categorizing laboratories by the types of activity performed would be useful when comparing capacity utilization and financial performance of individual laboratories.

Presently, these activity characteristics are not used to organize or categorize laboratories for performance comparison.

2. Research and Engineering (4.0) Laboratory Organization

The Research and Engineering (4.0) competency laboratories are organized into three distinct levels, aligning capabilities with primary RDT&E mission areas. The first level, Level I, divides the 350 Research and Engineering (4.0) laboratories into the following primary RDT&E mission areas:

- Air Vehicle RDT&E Facilities
- Aircrew Systems RDT&E Facilities
- Air Platform Interface (API) RDT&E Facilities
- Avionics RDT&E Facilities
- Mission System RDT&E Facilities
- Propulsion Systems RDT&E Facilities
- Ship and Shore Electronic Systems RDT&E Facilities
- Training Systems RDT&E Facilities

Laboratories belonging to the Level I, Aircrew Systems RDT&E Facilities mission area were chosen as the test group to provide data for this thesis. The Aircrew Systems laboratories are a subset of the Research and Engineering (4.0) competency group and are identified as the 4.6 series of laboratories. Forty-six individual 4.6 laboratories are assigned to the Aircrew Systems RDT&E Facilities mission area.

The second level, Level II, subdivides each Level I mission area into categories of functionally similar laboratories. For example, within the Level I category, Aircrew System RDT&E, there are nine different Level II functional categories (see Table 2.1).

LEVEL I Aircrew Systems RDT&E Facilities
LEVEL II 1. Advanced Crewstation Technology Labs 2. Aircraft Integration / Test Labs 3. Aircrew Altitude Protection & Breathing System Facility 4. Aircrew Protection and Survival Equipment RDT&E 5. Crashworthy System RDT&E Facility 6. Crew Systems Integration Labs 7. Crewstation Transparency and Lighting Labs 8. Escape System RDT&E Facility 9. Thermophysiology Research Facility

Table 2.1 4.6 Level II Laboratory Categories

Each of the Level II laboratory groups listed in Table 2.1 provides support to meet Level I Aircrew System mission requirements.

The third level, Level III, identifies each individual laboratory by its specific area of expertise. An example of the Level II group is Advanced Crewstation Technology Laboratories, which includes nine individual (Level III) laboratories, each with its own dedicated space and equipment. Table 2.2 provides an example.

Level II Advanced Crewstation Technology Labs
Level III 1. Advanced Technology Crew Station – JSF 2. Cockpit Crewstation Integration Facility 3. CTL Computer Operations Facility 4. CTL Data Reduction & Task Analysis Lab 5. CTL Helmet Mounted Display/Cueing Facility 6. CTL Mission Control Center 7. CTL Video Extraction and Activity Recording Labs 8. Laboratory Instrumentation Storage 9. Man Machine Integration Lab

Table 2.2 4.6 Level III Laboratories

The Level III laboratories are individual entities, coordinating operations with their Level II group of laboratories. Each Level III laboratory exists as either a stand-alone laboratory, capable of full process completion of RDT&E tasks, or as a small technical support space, integrated as a technical component of its Level II laboratory function. This distinction is not made clear under the existing laboratory structure, but may be important when comparing laboratory productivity at the Level III organizational level.

The focus of this thesis is centered on the Aircrew Systems (4.6) Level II laboratories. The data collected from these laboratories will be applied to the capacity utilization and productivity models and techniques discussed in Chapters V and VI. The Aircrew Systems RDT&E facilities represent one segment of the overall NAWCAD RDT&E laboratory organization. The nine Aircrew Systems (4.6) Level II laboratory groups, consisting of 46 individual Level III laboratories, have laboratory activity characteristics similar to the 67 Research and Engineering (4.0) competency Level II laboratories. These characteristics are also similar to those found in the Test and Evaluation (5.0) competency laboratories, but due to the limited focus of this research, a comprehensive description of (5.0) laboratory activity will not be presented.

3. Research and Engineering (4.0) Laboratory Financial Management

The accounting and financial management of Research and Engineering (4.0) laboratory activity is another element of the organization that must be defined to ensure

proper measurement of performance. The Aircrew Systems (4.6) laboratories are funded through the Navy Working Capital Fund (NWCF). Each of the Aircrew Systems (4.6) laboratories is set up as a NWCF account and must plan and execute its yearly budget based on expected levels of customer/program requirements and operating costs. The goal is to achieve zero net gain or loss at the end of the fiscal year when comparing actual laboratory revenue with all costs allocated to the NWCF laboratory account. Revenue is generated from the fees charged to paying customers of laboratory services. Laboratory services are primarily used by DOD program sponsors, but services are also available through contract agreements for non-DOD customers requiring the unique RDT&E capabilities that the NAWCAD facilities can provide. (Collier, 1998)

Presently, the Research and Engineering (4.0) competency facilities do not receive congressionally appropriated funds other than NWCF account dollars. The Test and Evaluation (5.0) competency facilities do receive appropriated Major Range and Test Facility Base (MRTFB) funds, which provide supplemental funding for federal RDT&E activities determined to be critical DOD or national assets. The amount of MRTFB funds distributed to the Test and Evaluation (5.0) competency laboratories in FY1997 was $80 million. MRTFB funds are intended for any DOD asset meeting congressional specifications and are not specifically restricted to Test and Evaluation (5.0) laboratories. It has been policy, set at the local (NAWCAD) level, not to fund Research and Engineering (4.0) competency laboratories with MRTFB funds. (Runion, 1998)

Although not all of the NAWCAD laboratories are presently funded as NWCF accounts, there are indications in the Defense Reform Initiative that accounting and financial management of all RDT&E facilities will be standardized to conform to best business practices of full-cost accounting. The NWCF is identified as the DOD financial management system most capable of achieving these accounting goals. (Defense Reform Initiative, 1997) The Aircrew Systems (4.6) laboratories NWCF account structure is being reviewed by management as the potential standard for all RDT&E laboratories, and initiatives have recently been put in place to convert other NAWCAD laboratories to the NWCF budget accounting system (Collier, 1998).

The Aircrew Systems (4.6) laboratories operating as NWCF accounts charge customers a fee for laboratory services and are classified as Rated Service Accounts (RSA). RSA laboratories charge customers for laboratory services based on a pre-set hourly laboratory rate. Rates are determined on a yearly basis, calculated by using projected levels of demand for laboratory activities and assigning an hourly rate that will produce a total revenue amount equal to the expected laboratory costs assigned for the year. The rates are set and reviewed during the year prior to execution through an internal budget review process, and are published as a constant rate for the entire execution year. Under the existing accounting system, the costs assigned to laboratory activities consist of direct operating costs and do not include indirect cost items such as production overhead and general and administrative costs. Table 2.3 identifies the types of costs used to determine FY1997 RSA laboratory hourly rates.

LAB 4.X 1997 OPERATING COSTS			
Maintenance		Operations	
Contracts	$113,000	Contracts	$116,000
Maintenance	$ 40,600	Consumables	$ 15,000
Travel	$ 1,600	Travel	$ 14,700
Labor	$183,000	Labor	$206,000
		Training	$ 9,000
		Utilities	$ 1,600
Total Maint	**$338,200**	**Total Ops**	**$362,300**

Table 2.3 Example of Costs assigned for laboratory rate determination

The calculated rates, therefore, reflect the projected amount needed to recover all direct costs associated with the laboratory, but do not account for indirect costs charged to overall NAWCAD facilities. In FY1997, NAWCAD RDT&E indirect overhead and general and administrative costs totaled $140 million and accounted for one quarter of all costs attributed to NAWCAD RDT&E facilities. (Runion, 1997) In recognition of the DOD directive toward full-cost accounting of activities, these indirect costs will be incrementally added to the assigned laboratory costs over the next three years. The increase in the cost base for RSA laboratories will drive laboratory rates up, assuming all other variables are held constant. Increased rates may drive demand for laboratory services down, which would subsequently provide pressure for additional rate increases to cover the loss in volume of activity. This self-perpetuation of rate increases is a potential problem facing NAWCAD RDT&E laboratories as they shift to a full-cost system. (Runion, 1998)

Some if not all of the additional costs allocated to laboratories can be countered with improvements in laboratory efficiency and productivity. Reducing infrastructure

and improving laboratory productivity are two methods identified by facilities managers to better manage available resources and reduce costs. (Collier, 1998) Accurate measures of capacity utilization and productivity are necessary for management to focus on appropriate business decisions influencing the efficient use of resources. The next chapter reviews potential models and measures of capacity utilization and productivity followed by identification of models and measures suitable for the NAWCAD RDT&E laboratory organization.

III. CAPACITY UTILIZATION AND PRODUCTIVITY

A. LITERATURE REVIEW

Business scholars and industry professionals have generated extensive research in efforts to determine levels of capacity and proper methods of measuring and accounting for capacity utilization. Effective management and efficient use of capacity are integral components of production oriented industry; there is abundant literature published in the area of capacity utilization in production manufacturing. A search of industry capacity related literature published since 1980 found over 300 articles focused on capacity utilization in production and manufacturing environments. The methods of measuring output as an indicator of capacity utilization in manufacturing industry are relatively well defined and have become accepted as business tools necessary to compete in today's manufacturing marketplace. Nonetheless, capacity and capacity management remain essentially elusive concepts. No single tool or single view of capacity management is best. (McNair and Vangermeersch, 1996)

1. Research and Development (R&D) Industry Review

No standards could be found to measure capacity utilization and performance of research and development (R&D) activities. A variety of different approaches to measuring capacity utilization were found, but few have been universally accepted, and none have been established as a standard for R&D activity. A 1996 Conference on

Performance Measurements for R&D, organized by the International Quality and Productivity Centre, Central Research Laboratories, Middlesex, UK, concluded that there are few universal measures and that each company must select, from a wide array of measures and approaches, a configuration that matches the requirements of each situation (Nixon, 1997). The conference report reviewed presentations given by three R&D industry management consultants, and summarized the content of nine papers written by a variety of companies focused on the implementation and operation of R&D performance measurement systems. (Nixon, 1997)

The conference report confirms that measurement of R&D production and capacity utilization is complex and difficult to define and quantify (Nixon, 1997). The nine papers presented at the conference, based on practices in Corporate Research Laboratories, emphasize that there is increased interest in performance measurements for R&D. Yet, no one universal approach exists. Each organization has developed a unique method achieving varying degrees of success. One consistent problem is the difficulty in defining output, exemplified in the following excerpt from the conference report:

> Richard Duggan, Senior Advisor on Innovation, DTI, related his experience as head of the Unilever Research Laboratory when he was challenged to improve output by 15%. The first problem was to define output; MIT's advice to him was that it was impossible to measure the output of R&D but that it was possible to monitor whether the most important parameters influencing output were improving or not. Changes could be measured and it was decided to measure and manage the use of scientists' time, working space and project completion time in order to bring about the required R&D output improvement. The programme achieved its goals, and the value of the space saved (with the help of interior space architect, David Leon) funded the implementation. (Nixon, 1997)

2. General Accounting Office Report on RDT&E Infrastructure

Other examples of industry practices are detailed in a General Accounting Office (GAO) report published in January 1998 titled *Best Practices, Elements Critical to Reducing Successfully Unneeded RDT&E Infrastructure*, which analyzed approaches used by organizations outside of the federal government to realign RDT&E infrastructure. The GAO report states that a clear relationship exists between the recent trend in industry of restructuring and reengineering and the need for accurate capacity utilization and productivity measures. GAO examined restructuring efforts by two organizations–the Boeing Company Defense & Space & Defense Systems Group and the Defence Research Agency within the British Ministry of Defence–both of which reduced substantially their laboratories' infrastructure and costs. (GAO, 1998)

The approach taken by each organization included several common elements. Both organizations (1) developed core missions and aligned them with their customers' needs, (2) determined what infrastructure they had and how it supported their missions,

and (3) collected accurate, reliable, and comparable data about their facilities across-the-board to reduce confusion, prevent facility officials from claiming they should be exempted from restructuring, and reduce their assertions that the facilities were unique or incomparable. One of the critical elements identified as a key to their success was accurate, reliable, and comparable data that captured total infrastructure costs and utilization rates for each affected activity. (GAO, 1998)

Both Boeing and the British Defence Research Agency discovered that their financial management systems could not capture or evaluate either the total costs of operating their labs or the facility utilization rates. Because accurate, reliable, and comparable data on infrastructure costs and utilization rates were critical, both organizations developed standardized data collection instruments to capture necessary details about their infrastructure. The Boeing Company Defense & Space Group included details about laboratory product areas, unique capabilities, equipment values, utilization rates, maintenance costs, personnel costs and capabilities, anticipated capability requirements, and potential consolidation/closing requirements. (GAO, 1998)

The data collected were analyzed by laboratory function. Functional categories tied each laboratory's activities to its primary mission. Brainstorming sessions listed 45 to 50 functions, which were winnowed to 15 prime functions. Categorization of laboratories into functional groups enabled the data to be compared among laboratories of similar function.

The question of how to capture accurate utilization rate data is not addressed in the report. Unfortunately, the specific details of Boeing's effort in developing utilization measurement devices have not been made available to sources outside of the organization. Although the report does not specify the metrics used to measure utilization rates, it does emphasize that multidisciplinary review teams were used to validate and analyze the data. The review teams included scientists, strategic planners, financial experts, accountants, engineers, and laboratory operations specialists. This cross section of organizational expertise ensured that accurate and comparable data were being obtained and allowed laboratory personnel to participate in the data collection process. (GAO 1998)

3. National Aeronautical and Space Administration (NASA)

Specific examples of capacity utilization metrics designed for RDT&E activities are found in methods used by the National Aeronautical and Space Administration (NASA) laboratories. (EMA, 1998) Table 3.1 identifies utilization criteria for their RDT&E facilities, including Facility Type, Unit of Utilization Measure, and Baseline Use Measure. NASA has incorporated the concept of Equivalent Utilization Days (EUD) for certain types of facilities as a standard against which to measure actual utilization. For example, a baseline of 220 EUD days per year represents the number of EUD days that the facility is available for testing, including time for test article prep, test ops, and tear down, but excluding adverse weather impacts, normal maintenance and other down time.

The actual usage is compared to the baseline of 220 EUD days and presented as a percent of baseline. (Smith, 1998)

NASA FACILITIES UTILIZATION CRITERIA		
FACILITY TYPE	UNIT OF UTILIZATION MEASURE	BASELINE USE MEASURE
Wind Tunnels, large vacuum chambers, flight simulators, engine test facilities and other research and development and test facilities	Equivalent Utilization Days (EUD) facility was occupied for testing. An EUD = one 8 hr shift; maximum EUD/Day = 3. This unit of measure is devised to show use in flexible but uniform terms – regular, periodic, or varying shift operations versus the baseline.	220 EUD days per year facility is normally available for testing including time for test article prep, test ops, and tear down, but EXCLUDING adverse weather impacts, normal maintenance and other down time.
Laboratories	An assessment of the level-of-use or need for the housed lab equipment, or population housed in lab area.	100% if all equipment is used at least seasonally or is needed for future activities, or if more appropriate, rated population @ 300 Net Square Feet per Person
Computer Facilities	EUD days the facility housed an active ADP operation.	260 EUD/year facility is normally available to support ADP operations

Table 3.1 NASA Facilities Utilization Criteria (From EMA, 1998)

In other laboratory settings, NASA uses a separate metric. An assessment of the level-of-use or need for the housed lab equipment is used as the Unit of Utilization Measure. The baseline for laboratory equipment utilization is set at 100 percent as long as all equipment in the lab is used at least seasonally or is needed for future activities. The lab assessment of actual use of equipment is reported as a percent of the baseline. Details are not provided about NASA's assessment techniques for determining level-of-use of laboratory equipment. (EMA, 1998)

4. Office of the Inspector General Audit Report on DOD Resource Utilization (RUMS)

Another application of RDT&E associated utilization metrics is found in a 1995 Office of the Inspector General Audit Report on DOD Resource Utilization. (DOD, 1995) The Resource Utilization Measurement System (RUMS) was designed to capture utilization rates of major DOD Test ranges in response to 1995 Base Realignment and Closure (BRAC) requirements. The equations used to measure utilization and efficiency are based on ratios of resource availability and use as described below:

$$\textbf{UTILIZATION} = (C + D)/(A + D)$$

$$\textbf{EFFICIENCY} = (A - B)/A$$

A = Time the resource was made available/staffed to support paying customers under actual staffing conditions. It does not include excess use above budgeted capacity. But it does include unplanned lost time due to weather and periods of non-use if people were available in a pay status to operate the facility.

B = Unscheduled Non-Availability due to external constraints (i.e. weather, unscheduled maintenance, etc.).

C = Use of a resource paid for by a customer (includes set-up and teardown, if they preclude use of the resource by another customer).

D = Use of a resource in excess of the normal resource budgeted capacity.

Example:

	Hours		
A =	1500	UTILIZATION = (1400+500)/(1500+500)	= 95%
B =	30		
C =	1400	EFFICIENCY = (1500-30)/1500	= 98%
D =	500		

The methods of measuring utilization rates used in the audit report were developed specifically for Test Ranges and did not address other RDT&E facilities. No published references were found noting application of the RUMS equations for RDT&E laboratory settings. It is also important to note that the audit team experienced difficulty in obtaining accurate, reliable data from the test sources for their study (DOD, 1995). Similar problems were cited in the cases of Boeing and the British Defence Research Agency (GAO, 1998). The financial management system could not accurately capture the total cost of operating or the facility utilization rate data required. (DOD, 1995)

B. BENCHMARK APPLICATION

The lack of research and development industry standards of performance and measurement reduces the potential for benchmark applications for NAWCAD RDT&E laboratories. The inconsistency of methodology and lack of available industry specific information about capacity utilization metrics limits detailed review. The Boeing RDT&E laboratory organization displays the highest degree of similarity with the NAWCAD RDT&E labs. A more detailed review of the capacity utilization metric developed by Boeing may provide potential benchmark measures for NAWCAD and other DOD laboratories. In the absence of compatible RDT&E benchmark measures, NAWCAD should establish internal standards of performance for laboratory capacity utilization and productivity. The following chapters present potential models and

techniques for measuring capacity utilization and productivity of NAWCAD RDT&E facilities.

IV. REVIEW OF CAPACITY UTILIZATION MODELS

A. INDUSTRY CAPACITY UTILIZATION MODELS

No single, magical capacity number will work in all companies, all settings or all decision contexts. Rather, an overall philosophy or approach to capacity supports a company's efforts to improve performance through better management and utilization of its resources (McNair and Vangermeersch, 1996). The financial and accounting professions have produced a variety of models addressing capacity utilization with a focus on effectively managing the cost of capacity. The capacity utilization and cost models are designed to provide management with the necessary tools to achieve maximum utilization of company resources. Consisting of a set of action-based tools for making products and providing better, faster and cheaper services to customers, the development of capacity management systems is synonymous with best management practice in management accounting (McNair and Vangermeersch, 1996).

Applications of concepts utilized by the existing capacity utilization and cost models appear to have the potential to enhance the development of a capacity management system for NAWCAD RDT&E laboratories. Table 4.1 provides a list of existing models identified in the literature and selected attributes of the models. A review of the capacity management models and their respective capacity cost measurement tools and techniques is presented in this chapter.

Features / Model	Capacity Baseline Emphasized	Primary Time Frame of Analysis	Organizational Focus
Resource Effectiveness Model	Theoretical Capacity	Short-to long-term	Process/Plant/ Company Levels
Capacity Utilization Model	Theoretical Capacity	Short- to Intermediate-Term	Process/Plant/ Company Levels
Capacity variance Model	Theoretical Capacity	Short- to Intermediate-Term	Process/Plant Levels
CAM-I Capacity Model	Theoretical Capacity	Short- to Long-Term	All Levels (Potential)
CUBES Model	Theoretical Capacity	Short- to Intermediate-Term	Process/Plant/ Company Levels
Cost Containment Model	Implicit Theoretical Capacity	Intermediate-Term	All Levels (Potential)
Gantt Idleness Charts	Practical Capacity	Short-term	Process Level
Supplemental Rate Method	Practical Capacity	Short-term	Process/Plant Levels
Theory of Constraints Capacity Model	Practical Capacity (Marketable)	Short- to Intermediate-Term	Process/Plant/ Company Levels
Normalized Costing Approach	Normal Capacity	Intermediate-Term	Process/Plant Levels
ABC and Capacity Cost Measurement	Normal Capacity	Short- to Intermediate-Term	Process/Plant/ Company Levels
Integrated TOC-ABC Model	Various	Short- to Intermediate-Term	Process/Plant/Value Chain Levels

Table 4.1 Tools and Techniques for Measuring the Cost of Capacity
(From McNair and Vangermeersch, 1996)

Each capacity utilization model and cost measurement tool listed takes a different approach to measuring the utilization and cost of capacity. These models are grouped according to the capacity baseline measure they emphasize: theoretical, practical, or normal capacity. A definition of each of these baseline measures is listed below:

- *Theoretical capacity* – the optimal amount of work that a process or plant can complete using a 24-hour, seven-day operation with zero waste, i.e., the maximum output capability, allowing no adjustment for preventive maintenance, unplanned downtime, and shutdown.

- *Practical capacity* – the level of output generally attainable by a process, i.e., theoretical capacity adjusted downward for unavoidable nonproductive time: such as set-ups, maintenance or breakdowns.

- *Normal capacity* – the average, expected, utilized capacity of a machine, process or plant/unit over a defined period of time (day, week, month, year).

Another important dimension of capacity cost management is organizational focus. The issues impacting capacity cost management at the process level often differ from those faced at the plant or company level. Each model focuses on one or more of the following organizational levels: (1) process level, (2) plant or sub-unit level, (3) company level, and (4) value chain level. (McNair and Vangermeersch, 1996) An organization and its existing structure and capabilities define the first three levels. The process level, which can range from one task to an assembly line, focuses on individual units of output. The plant or sub-unit level suggests several processes and several unique types of outputs. At the company level or strategic unit, many different plants or sub-units combine to create a complex organization that serves many markets with many different types of products and services. Finally, the value chain level shifts its attention to all of the activities and resources of all organizations used to bring a good to the consumer.

The time frame of decision analysis is another factor to consider when reviewing different models. Model assumptions about the length of time involved in affecting capacity utilization issues have a direct impact on an organization's ability to change the cost and management of its capacity. In the short run, theoretical capacity is constant;

very little can be done to change the theoretical capacity of a process. The focus in the short-run model is on improving the utilization of existing resources and processes.

As the time frame extends to the intermediate term, an organization can act to change how the process operates, impacting the theoretical capacity of the process, without changing the physical structure of the process. The focus in the intermediate-run model shifts to maximizing the flexibility of existing processes in order to decrease future investment requirements. Finally, in the long-run, a wide range of techniques and measures can be used to adjust capacity and its utilization. (McNair and Vangermeersch, 1996)

The issues of time frame of analysis, organizational focus, and baseline capacity measures are dimensions that can be used to select a model from among the various capacity cost measurement models. Matching these model characteristics to organizational objectives will help guide the selection process. Other characteristics common to capacity management models are classifications of use or deployment of capacity.

Understanding the terms used to describe capacity deployment is essential to building successful utilization measures and communicating their results to management. The following categories are commonly used in the models to break down overall capacity into specific types of deployment.

- *Productive capacity* – capacity that provides value to the customer. Productive capacity is used to produce a product or provide a service. It is based on the theoretical, or maximum, value-creating ability of the company's resources

- *Nonproductive capacity* – capacity neither in a productive state nor in one of the defined idle states. Nonproductive capacity includes setups, maintenance and scrap

- *Planned nonproductive capacity* – capacity planned for use that is temporarily out of use due to process variability, such as the lack of materials, machine or process breakdown, or delays

- *Planned idle capacity* – capacity not currently scheduled for use; planned idle capacity might be planning for preventive maintenance

- *Excess capacity* – permanently idle capacity that is not marketable or usable under existing operating or market or policy conditions

(McNair and Vangermeersch, 1996)

B. MODEL FEATURES AND COMPARISONS

The different features of each model are described in the Management Accounting Practices Handbook, *Measuring the Cost of Capacity*, 1996, and are summarized in the following section to provide a general understanding of model characteristics and to facilitate comparison between models:

- *Resource Effectiveness Model*:
  - ➢ Analyzes economic impact of capacity management decisions
  - ➢ Assumes that "zero waste" is the goal
  - ➢ Supports decisions across all time frames
  - ➢ Provides an integrated financial and operational analysis of resource decisions
  - ➢ Recommended for firms that use process, cellular, or assembly line manufacturing methods.

- *Capacity Utilization Model:*
  - ➢ Focuses on waste as key capacity measure
  - ➢ Separates causes of capacity waste by time frames and actionability
  - ➢ Supports decisions for short-to intermediate-time frames of analysis
  - ➢ Consists of systemic capacity measures

- Recommended for use in conjunction with other continuous improvement-supporting capacity models, such as *Theory of Constraints*

- *Capacity Variance Model:*
  - Details actual performance against theoretical capacity
  - Identifies causes of capacity losses
  - Supports decisions for short- to intermediate-time frames of analysis
  - Can be tracked against improvement goals
  - Recommended for companies that wish to add some level of capacity cost management reporting to existing management report packages.

- *CAM-I Capacity Model:*
  - Integrates capacity data across many dimensions
  - Ties to the financial reporting system
  - Supports decisions for short- to long-time frames of analysis
  - Supports and integrates activity-based costing
  - Uses time as a unifying measure
  - Recommended for companies to obtain the maximum benefit from data warehouse/database capabilities to provide an integrated, flexible reporting package to be used across an organization.

- *CUBES Model:*
  - Integrates financial and nonfinancial data
  - Builds from activity-based costs
  - Supports decisions for short- to intermediate-time frames of analysis
  - Provides a dynamic analysis and least-cost solution
  - Recommended for companies facing high capital investment with short product life cycles

- *Cost Containment Model:*
  - Focuses on support/service costs
  - Supports/integrates with activity-based costing
  - Supports decisions for intermediate-time frame of analysis
  - Builds on value-added, market-based models
  - Recommended for companies that are conducting competitive bidding for internal services and benchmarking studies that focus on costs per process/activity

- *Gantt Idleness Charts:*
  - Supports decisions for short term time frame of analysis
  - Focuses on the process level of the organization
  - Summarize performance in operational and financial terms
  - Detail costs and causes of idleness
  - Recommended for factory environments using departmental or cellular manufacturing approaches

- *Supplemental Rate Method:*
  - Supports decisions for short-term time frame of analysis
  - Focuses on the process and plant levels of the organization
  - Focuses on profit impact of idleness
  - Supports internal and external reporting
  - Recommended for small companies with easily defined capacity costs and issues

- *Theory of Constraints Capacity (TOC) Model:*
  - Supports decisions for short-to intermediate-time frame of analysis
  - Highlights key constraints inhibiting process performance
  - Useful in plants or processes using TOC in their management processes
  - Recommended for companies using TOC approaches elsewhere in the organization such as external and TOC-based management reporting

- *Normalized Costing Approach:*
  - Supports decisions for intermediate time frame of analysis
  - Focuses on the process and plant levels of the organization
  - The capacity of a process is determined using practical capacity baselines set over a three to five year period
  - Normalized cost is determined by combining cost and capacity information to create a cost estimate under a given set of operating conditions
  - Recommended for complex manufacturing companies

- *Activity Based Costing (ABC) and Capacity Cost Measurement:*
  - Supports short-to intermediate-time frame of analysis
  - Fits into activity-based cost model
  - Reports both the quantity and cost of idle capacity
  - Strong emphasis on resources
  - Serves as a bridge between more conventional views of capacity cost management and ABC

- *Integrated TOC-ABC Model:*
  - Uses mathematical modeling to solve for optimal capacity utilization
  - Focuses on product mix and marginal revenue
  - Provides a superior solution to a pure TOC or pure ABC methodology when at least one bottleneck operation exists

(McNair and Vangermeersch, 1996)

An expanded comparison chart listing features of the different capacity management models is presented in Appendix A.

Aligning model attributes with NAWCAD objectives for capacity utilization management is an important step in the model selection process. Interviews with NAWCAD facility and laboratory managers identified management criteria for development of capacity utilization measures. Models and measures selected must provide management with information relevant to decision-making in these areas. The following list is a summary of issues considered by management to be important in the development of NAWCAD RDT&E laboratory capacity utilization measures:

- Capital investment decision analysis
- Business strategy development
- Outsourcing/Consolidation decision analysis
- Laboratory facilities space limitations/allocation decision analysis
- Identify NAWCAD business strengths and weaknesses
- Identify full-cost of capacity and laboratory utilization
- Integrate with activity-based cost system
- Laboratory rate structure management (rate reduction)
- Provide accurate, relevant financial information about laboratory activity

- Establish system to anticipate and accommodate DOD RDT&E infrastructure reorganization requirements (BRAC, Defense Reform Initiative)
- Establish comparison baseline for competing laboratories
- Improve laboratory efficiency
- Determine appropriate laboratory productivity measures

The issues pertinent to NAWCAD RDT&E laboratory capacity utilization highlight a need for an organizational focus at all levels. Information provided by measures of capacity utilization is required for top-level business strategy development as well as the operational level management of laboratory activity. Additionally, the need for short-, medium-, and long-term time frame analysis is implied by the need for short-term yearly rate structure management, medium-term requirements associated with DOD RDT&E infrastructure reorganization, and long-term capital investment decision analysis. Implementation of full-cost and activity-based cost (ABC) accounting systems throughout the NAWCAD organization mandates model compatibility with ABC systems. Changes in the financial management system for NAWCAD such as the proposed Cost Based Management Tool (CBMT) and ABC will require a strong tie between the operational and financial processes within the RDT&E organization. Finally, NAWCAD facilities managers desire decision-making information for both the planning and control of RDT&E capacity utilization through better management reporting and analysis of laboratory activity. (Collier, 1998)

The characteristics for each of the twelve models are referenced against the specific NAWCAD RDT&E capacity utilization management objectives in Table 4.2. Of

the twelve models listed, the one that best meets these criteria and can be applied to the unique research and development environment is the CAM-I Capacity Model developed by the Cost Management Systems Program of the Consortium for Advanced Manufacturing – International (CAM-I) Capacity Group. (Klammer, 1996)

MODEL CHARACTERISTICS	Organizational Focus at All Levels	Short- Medium- and Long Time Frame of Analysis	Support of Activity Based Costing (ABC) Systems	Provides Both Planning and Control of Capacity Utilization	Strong Tie between Operational and Financial
Resource Effectiveness Model		X	X		X
Capacity Utilization Model			X	X	X
Capacity Variance Model					X
CAM-I Capacity Model	**X**	**X**	**X**	**X**	**X**
CUBES Model			X	X	X
Cost Containment Model	X		X		
Gantt Idleness Charts					
Supplemental Rate Method					X
Theory of Constraints Capacity Model				X	
Normalized Costing Approach			X	X	
ABC and Capacity Cost Measurement					X
Integrated TOC-ABC Model			X	X	X

Table 4.2 NAWCAD Objectives Vs Model Characteristics

V. CAM-I CAPACITY MODEL

A. CAM-I CAPACITY MODEL REVIEW

The CAM-I capacity model is primarily a strategic communication tool, designed to support the strategic decision process by helping managers understand and define the many states of capacity, measure these states, and then communicate them in a simple format (McNair and Vangermeersch, 1996). This economic model is a tool that can be used to improve the productivity of existing capacity and significantly influence the capital investment decision process. Based on the CAM-I Capacity Interest Group publication *Capacity Measurement & Improvement, A Managers Guide to Evaluating and Optimizing Capacity Productivity* (1996), an overview of the model is presented here to provide a baseline understanding of its components and application considerations.

There are several concepts at the core of the model design that need to be defined. The model uses a baseline measure of maximum capacity termed “rated capacity”. The common element defining use of capacity is time. Rated capacity is a time measure based on twenty-four hours a day. The cost of this capacity is 100 percent of the total cost assignable to the process. The model provides a framework from which to translate capacity utilization from standard operational units of time into financial units of dollars (cost). This is accomplished through the use of a basic template that displays capacity utilization as a function of time divided into three distinct categories: (1) idle capacity, (2)

nonproductive capacity, and (3) productive capacity. Financial data can then be assigned to each of the categories indicating distribution of process costs. (Klammer, 1996)

The model subdivides total rated capacity into more specific elements of capacity. The summary capacity model shown in Figure 5.1 is an example of the basic template used to subdivide total or rated capacity into idle, nonproductive, and productive capacity.

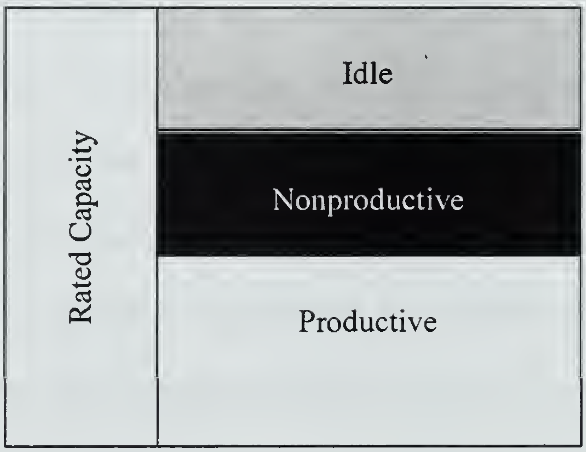

Figure 5.1 CAM-I Summary Capacity Model

The summary model can be expressed as:

Rated Capacity = Idle + Nonproductive + Productive Capacity

The full capacity model, shown in Figure 5.2, further divides idle, nonproductive, and productive capacity into specific classes providing a greater level of detail for identifying more specific uses of rated capacity.

	Summary	Industry Specific	Strategy Specific
Rated Capacity	Idle	Not Marketable	Excess not Usable
		Off-limits	Management Policy
		Marketable	Idle but Usable
	Non-Productive	Maintenance and Setups	Scheduled
			Unscheduled
		Standby	Variability Suppliers/Customers
		Waste	Scrap and Rework
	Productive	Process Development	
		Product Development	
		Good Products	

Figure 5.2 CAM-I Full Capacity Model

The elements of the full capacity model are defined below:

- **Idle capacity** – Capacity not currently scheduled for use.
  The CAM-I Model breaks idle capacity into three specific classes:
  1. Idle not marketable: no market exists or management made a strategic decision to exit the market. This capacity is a target for abandonment.
  2. Idle off limits: capacity unavailable for use because of holidays, contract, or management policies or strategies.
  3. Idle marketable: a market exists but capacity is idle.

- **Nonproductive capacity** – Capacity not in a productive state or not in one of the defined idle states. Nonproductive capacity includes:
  1. Setups and maintenance: scheduled and unscheduled downtime
  2. Standby: nonproductive because of variability caused by suppliers, customers, or internal operations.
  3. Waste: may be scrap, rework, and yield loss.

- **Productive capacity** – Capacity that provides value to the customer. Productive capacity results in the delivery of good products or services. It may also represent the use of capacity for process or product development.

The summary capacity model (Figure 5.1) is incorporated as columns one and two of the full model (Figure 5.2). The summary capacity model provides the general state of capacity in a form that is useful for decision-makers. This information could be presented for an entire organization, a plant, a process, a production center, a machine, or an individual (Klammer, 1996). The full capacity model provides a comprehensive analysis of various states of capacity. The detailed specification of the types of capacity is particularly useful for business and operating teams focusing on using capacity more effectively. (Klammer, 1996) Two basic templates are used to display capacity utilization in units of time and cost. A basic time template is shown in Figure 5.3. The basic economic template is constructed by adding process costs to the raw time data and is shown in Figure 5.4. This information is particularly useful to management for evaluation of capacity utilization and productivity. The model provides clear communication of operational capacity utilization in terms useful for business decision-making. (Klammer, 1996)

<u>Equipment Set A</u>

Idle 2 hrs	Not marketable
	Off-limits
	Marketable
Non- productive 2 hrs	Standby
	Maintenance
	Setups
Productive 4 hrs	Process Development
	Product Development
	Good Products

Figure 5.3 CAM-I Basic Time Template

<u>Equipment Set A</u>

Idle $200K	Not marketable
	Off-limits
	Marketable
Non- productive $300K	Standby
	Maintenance
	Setups
Productive $500K	Process Development
	Product Development
	Good Products

Figure 5.4 CAM-I Basic Economic Template

B. CAM-I CAPACITY MODEL IMPLEMENTATION AND ADAPTATION FOR RDT&E LABORATORIES

Successful implementation of the CAM-I Capacity Model in a research and development environment requires a clear plan of action, including modification of the model to meet specific RDT&E requirements. Accordingly, adjustments to the model have been incorporated in this thesis to address the unique characteristics of the NAWCAD RDT&E laboratories. The goal of these adjustments is to provide measurement criteria that will accommodate the diversity and complexity of the RDT&E laboratory environment, and provide accurate information useful in the decision-making process. This section addresses model implementation procedures and highlights unique considerations for the RDT&E laboratory setting.

Initial model development should use historical data from the targeted area of capacity management. This focus helps develop an understanding of the current capacity. Applying the model to projections has the potential to provide the most value. The model could provide input to product investment decisions, capacity authorization decisions, strategic supplier management decisions, and strategic customer management decisions. (Klammer, 1996)

1. Model Implementation

The CAM-I Capacity Interest Group recommends a series of steps that are helpful in implementing the capacity model, as follows:

a) Organize the implementation team.

b) Determine management objectives.

c) Select a model presentation template.

d) Review element definitions.

e) Select the measurement period.

f) Identify and access operational data.

g) Identify and access financial data.

h) Summarize to level of required presentation model.

i) Monitor for results.

NAWCAD management as part of a comprehensive implementation plan should consider each of these steps. Further discussion of these steps highlights the unique adaptation considerations for the NAWCAD RDT&E laboratory environment, and provides additional information about characteristics and capabilities of the CAM-I capacity model.

a) Organize the implementation team

Successful implementation of the capacity model requires senior management and operation teams to reach a consensus on the need for the model

information (Klammer, 1996). Model presentation in this thesis should assist management in determining the level of need and use for the CAM-I model information.

b) Determine management objectives

Effective use of the model requires identification and communication of management objectives. The objectives may include idle capacity resolution (downsizing), increasing capacity flexibility, and identifying causes of variability and waste in laboratory activities. Each of these objectives influences the activities identified by the model and the presentation template(s) (Klammer, 1996).

c) Select a model presentation template

Different capacity templates support different business objectives. For example, if idle capacity identification is important to the organization, basic time and economic templates (Figures 5.3 and 5.4) can identify and communicate the different levels of idle capacity, the functional areas responsible, and the costs associated with that capacity.

d) Review element definitions

The model uses the language and definitions already in use in the organization. However, if the model is applied to multiple entities, i.e. laboratories, and a common language does not exist among these entities, a common set of terms needs to be established.

e) Select the measurement period

The model focuses on strategic decision processes. Measures that use quarterly and annual periods are typically more useful than daily and weekly reporting periods. In fact, frequent updates may contain distortions that would be harmful if used to make strategic decisions. More frequent measures may have value at specific operational levels. (Klammer, 1996)

f) Identify and access operational data

The model is an economic mirror of existing capacity (Klammer, 1996). States of capacity as defined by operations should be used in establishing the baseline of data to be input into the model. Operational activities that influence decisions are therefore highlighted by the model and translated into an economic presentation format.

g) Identify and access financial data

The model allows the user to focus on a subprocess within a larger process or activities within a process. Organizations with ABC systems probably already have financial data for these processes and activities. For organizations using less accurate overhead cost assignments, opportunities for improvement exist. Through a more detailed reporting of the different states of capacity the capacity model can help a company assign overhead to the most appropriate process and activity. (Klammer, 1996)

h) Summarize to level of required presentation model

Summary data are important to ensure that each level can understand capacity effects on their areas of responsibility. Who will be using the information determines what level of detail is required.

i) Monitor for results

Monitoring helps determine if operational and financial data collection and applications are accurately taking place. A plan to continually improve the operational and economic data should be established as an ongoing process.

2. Model Adjustments

The theoretical capacity used as the baseline capacity measure by the CAM-I capacity model is 24 hours a day, every day. The laboratories studied are government owned and operated. Over ninety percent of the scientists and technicians who operate the laboratories are civilian DOD personnel working daytime eight-hour shifts. (Collier, 1998) Under the present conditions, most of the laboratories studied are therefore occupied and operational for only the working hours described above. The CAM-I baseline capacity measure of 24 hours a day, every day of the year, is adjusted to eight hours per day / five days per week to represent a more practical baseline of maximum available capacity for the NAWCAD RDT&E laboratories. With this adjustment, total rated capacity is defined as eight hours per day / five days per week, excluding holidays.

C. CAM-I CAPACITY MODEL SUMMARY

The CAM-I Capacity Model is designed to provide as much or as little detail as management requires. The adaptation of the CAM-I model in this thesis provides examples of the NAWCAD RDT&E laboratory data presented in the summary capacity model format (Figure 5.1) and the basic time and economic template formats (Figures 5.3 and 5.4). These examples demonstrate the model's ability to effectively capture and communicate capacity utilization information. These templates represent the foundation from which other templates and tools can be generated, providing multiple layers of detail for capacity utilization analysis. For example, a template isolating idle capacity for a single process or piece of equipment can identify specific causes and costs of the idle state of capacity for that activity. In addition, a summary model of overall NAWCAD RDT&E capacity can be used to help establish and monitor strategic infrastructure reduction goals.

The data requirements for detailed presentation of all of the additional templates are beyond the scope of the thesis. For example, accurate utilization data at the Level III organizational level can provide the user with a more detailed view of laboratory capacity. Practical constraints of time and resources limited this research to the Level II organizational level. However, NAWCAD should review the need for additional levels of capacity reporting and implement the templates and tools necessary to collect and process appropriate decision-making information. Examples of additional templates are found in the CAM-I Capacity Interest Group publication *Capacity Measurement &*

Improvement, A Managers Guide to Evaluation and Optimizing Capacity Productivity (1996).

Capacity utilization presented in the CAM-I capacity model is one approach to measuring performance for RDT&E laboratories. Acquiring accurate, dependable time and cost data is critical to proper analysis. A database of accurate cost data established as part of the financial management system can also be used to generate additional financial productivity measures. Chapter VI introduces potential financial productivity measures for NAWCAD RDT&E facilities, incorporating existing accounting procedures and applying financial ratio analysis to determine laboratory productivity in terms of cost and revenue relationships.

VI. RDT&E FINANCIAL PRODUCTIVITY MEASURES

A. OVERVIEW OF RDT&E FINANCIAL PRODUCTIVITY MEASURES

In an effort to manage Defense activities more in line with best business practices of the American commercial sector, an increased emphasis is placed on improving productivity through cost efficiency and recovery of full costs associated with activities and products. Recovery of costs associated with RDT&E laboratories is dependent upon the amount of revenue generated from sponsor-funded projects and contract use of laboratory facilities and personnel. Identifying all costs and revenues associated with individual labs is essential in building proper performance measures.

The NAWCAD research and engineering 4.0 competency laboratories are financially managed as Navy Working Capital Fund (NWCF) accounts. NWCF accounts are designed such that the revenue generated by the account activity is sufficient to cover the portion of costs allocated to that account. Financial productivity for NWCF accounts can therefore be a measure of the laboratory's ability to recover all of its assigned costs for the Fiscal Year. However, the present system does not assign full cost to the individual laboratories. Cost items such as depreciation, general and administrative, and facilities overheads are not included as costs assigned to laboratory NWCF accounts (Runion, 1998). Incorporating full costs into productivity measures would provide

management with better decision-making information about the financial performance of laboratory facilities.

The recent emphasis on improving cost efficiency of DOD laboratories and test centers has resulted in the initiation of the development and implementation of a Cost-Based Management Tool (CBMT) designed to capture, display and archive comparable cost data associated with the operation of Defense RDT&E organizations. This Defense wide program has been directed by the Deputy Secretary of Defense to be fully operational by the end of Fiscal Year 1998 (Memorandum (i), 1997). The overall goal of the Cost-Based Management Tool is to provide executive level visibility of the full costs associated with DOD Laboratories and Test & Evaluation Centers. The Cost-Based Management Tool is not designed to account for revenue.

B. RETURN ON OPERATIONS INDEX AND OPERATING MARGIN

By the end of FY 1998, NAWCAD RDT&E laboratories will implement CBMT, and, as part of the process, will begin to collect detailed cost data across all spectrums of the organization. Until implementation of CBMT is complete, the RDT&E laboratory cost data are limited to the output of the existing financial management system. Since the present system for RDT&E operations does not account for full cost recovery of laboratory activity, the full cost and revenue data required for performance measurements described in this thesis were collected from sources both inside and outside of the existing financial management system. These data were used as input into the following

equation, the results of which are presented in Chapter VII, as a financial performance indicator designed to measure individual laboratory productivity:

Return on Operations Index (ROOI) = Total Revenue / Total Cost of Operations

The ratio of Total Revenue/Total Cost of Operations is an indicator of laboratory productivity from a NWCF perspective. It identifies what percent of all costs associated with a specific laboratory are offset by revenues generated by the laboratory. Results of less than 1.0 represent a loss. Additionally, the difference between revenue and full cost represents the laboratory's dollar contribution to the organization as a whole (operating margin), highlighting the total amount of dollar surplus or loss generated by laboratory operations. For example:

Laboratory 4.X	FY 1997 $'s
Total Revenue	$800,000
Total Cost of Operations	$1,000,000
Operating Margin	**- $200,000**

ROOI = $800,000 / $1,000,000 = .8

In this example, only 80 percent of the total cost of operations are recovered from laboratory generated revenue, resulting in a loss of $200,000 for the year.

Laboratories will be grouped into categories of similar operating characteristics to enable meaningful analysis and comparison of performance. The ROOI for each Laboratory will be rated against a benchmark ROOI for each category. The benchmark

ROOI represents the average ROOI for the laboratory category. This approach incorporates best business practices similar to corporate use of financial ratio analysis. Measuring productivity in terms of cost and revenue relationships, and comparing the results to industry standards, is a common practice in industry (Maher, 1997). Examples of corporate performance ratios include return on investment, return on total assets, and return on sales.

RDT&E facilities managers are also interested in utilization issues related to space allocation and capital investment decisions. Productivity per square foot is a common measure of facility utilization used in corporate merchandising and production industries. As long as appropriate parameters are defined, productivity per square foot is a useful comparison and decision analysis tool for facility space allocation issues. Measuring revenue, cost, and operating margin per square foot of facility space allocated to each lab allows for performance comparison from a space utilization perspective. For example:

Laboratory 4.X			FY 1997
Total Square Footage			10,000 sq ft
Revenue (per sq ft)	($800,000 / 10,000 sq ft)	=	$80.00 (per sq ft)
Total cost (per sq ft)	($1,000,000 / 10,000 sq ft)	=	$100.00 (per sq ft)
Operating margin (per square foot)		=	- $20.00 (per sq ft)

Facility space productivity measures, when compared across all labs as well as within specific categories, provide managers an additional financial tool for space allocation and capital investment decision-making.

C. PERFORMANCE COMPARISON CHART

The CAM-I Capacity model and the productivity measures presented thus far are tools designed to provide better information for business decision-making. Effectively presenting the results of these measures is critical to their successful implementation. A Performance Comparison Chart, combining the results from productivity measures and the CAM-I model, is shown in Figure 6.1.

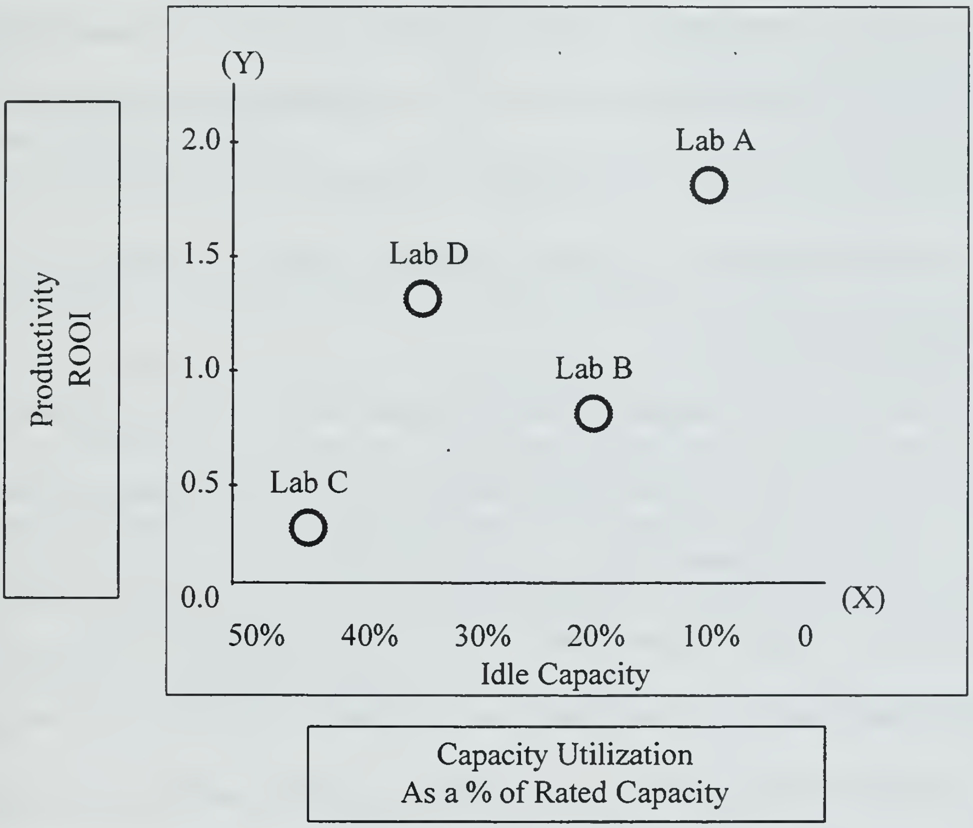

Figure 6.1 Sample Performance Comparison Chart

This chart presents critical capacity utilization and productivity information in a format that enables analysis across two dimensions of performance. The vertical axis (Y) displays productivity information, and the horizontal axis displays capacity utilization

information. When plotted in reference to each other, the relative financial strengths and weaknesses of laboratory capacity utilization and productivity are highlighted. Different regions of the graph identify areas of financial strength or weakness, dependent upon the specific data and scales used. In this example (Figure 6.1), ROOI is plotted against idle capacity. The upper right region of the chart indicates strong performance in both productivity and capacity utilization (Lab A). The lower left region indicates weak performance in both productivity and capacity utilization (Lab C). The center region indicates mid-range overall performance with varying combinations of productivity and capacity utilization (Labs B and D). The snapshot of laboratory performance provided by this chart can alert management to areas of business strength and weakness from a financial management perspective.

A comparison of performance for the mid-range Labs B and D in Figure 6.1 highlights the charts ability to communicate different levels of performance significant for strategic analysis and decision-making. Lab B ROOI is less than 1 with 20% idle capacity, while Lab D ROOI is greater than 1 with 35% idle capacity. If the primary objective for management is to maximize use of capacity, Lab B is the stronger performer, and if financial productivity is the primary objective, Lab D is the stronger performer. The overall performance of both Labs is very similar if the two performance parameters are given equal strategic importance. In this case, the chart highlights differences between the two similar Labs and alerts management to areas of business strength and weakness for each performance measure.

The specific data and scale used for each axis can be determined based on management preferences. Combinations of productivity and capacity utilization measures can be selected from any of the measures available. Four examples of Performance Comparison Chart options are presented below:

(Y) – Axis Productivity Measure		(X) - Axis CAM-I Capacity Utilization Measure
ROOI	Vs	Idle Capacity
ROOI	Vs	Productive Capacity Utilization
Operating Margin (per sq ft)	Vs	Idle Capacity
Total Operating Margin	Vs	Productive Capacity Utilization

Management can also indicate on the chart minimum acceptable levels of performance for each parameter. For instance, NAWCAD may set a minimum acceptable ROOI of 0.5 for its laboratories. The region on the chart of less than 0.5 ROOI can be highlighted, drawing attention to any result that is out of the acceptable range. Chapter VII provides specific examples and analysis of the Performance Comparison Chart incorporating the results of data collected for this thesis.

VII. DATA

A. DATA COLLECTION METHODOLOGY

This section addresses data collection methods used for the NAWCAD RDT&E research and engineering (4.0) activities and discusses difficulties in measuring capacity utilization in the RDT&E laboratory setting.

Research and development is not a production type of activity. Output is difficult to define and is not constant. This makes it difficult to define a measure of output. However, the factors that influence output can be identified. Equipment, facilities, and personnel are the primary resources that contribute to NAWCAD RDT&E laboratory output. The CAM-I capacity model is able to communicate utilization of these resources using time as a common measure of activity, while applying costs to the different types of activities to provide an economic analysis of utilization. Determining which of these factors are significant indicators of capacity utilization for laboratory facilities is critical to the success of the model in providing useful decision-making information to RDT&E managers.

Research and development activities rely heavily on the expertise and creativity of highly skilled personnel to produce output. Any attempt to measure the capacity of personnel would have to include both tangible and intangible factors. There can be little doubt that, in today's knowledge-based economy, intangible assets (like the programming

know-how of Microsoft) can be far more valuable than the tangible, "fixed" assets that dominate conventional balance sheets (Stewart, 1994). Measuring intangible assets, such as intellectual assets of research scientists, programmers, and technicians, that comprise the organization's available resources in a reliable, comparable way is very difficult. Qualitative methods of measuring the intellectual capacity of personnel in the RDT&E environment should be recognized as a viable input to overall capacity; however the focus of this research, in accordance with NAWCAD objectives, will concentrate on measurement of tangible factors such as equipment and facility use.

The recent reports calling for DOD RDT&E infrastructure reductions (GAO, 1998), along with the implementation of the Cost-Based Measurement Tool (Memorandum (i), 1998), have focused management attention on the need for accurate, reliable data on the use and costs associated with RDT&E infrastructure, i.e. facilities and equipment. Quantifiable measures must be used to provide comparable data across all laboratories. The CAM-I capacity model is designed to present capacity data in a format that facilitates comparison of capacity utilization across functions and activities, while providing a tool to establish internal benchmarks for business activities where industry standards do not exist (Klammer, 1996). A quantitative approach of measuring the use of laboratory equipment and facilities should give management a strong baseline of capacity utilization information vital to capacity and resource allocation decision-making.

1. Equipment Utilization

Unlike major production facilities, research laboratories utilize thousands of pieces of equipment designed for specific laboratory functions. The laboratories operate as separate entities, functionally aligned to support overall mission requirements, and house the equipment necessary to support their particular function. The types of equipment used are not standard from one laboratory to another. Large mechanical test devices such as horizontal accelerators, computers, specialized video analysis equipment, and aircraft cockpit simulators are just a few examples of the variety of equipment used in the laboratories.

One way to measure equipment use in a standard, comparable format is by using time as the baseline unit of measure. Allocating the rated capacity (total time the equipment is available for use) into different types of use (productive, nonproductive, and idle) describes equipment utilization in a common frame of reference. Utilization rates for the different types of equipment provide an indicator of overall capacity utilization for the laboratory. When compared to similar laboratories and equipment, the relative use of equipment for each laboratory can be evaluated as one indicator of overall capacity utilization. Accurate, dependable data are required for proper analysis. The measurement of equipment utilization in terms of time can be accomplished through a manual tracking system that records equipment activity on a daily basis. Table 7.1 is an example of a data collection form designed to record daily equipment use. (CMS, 1997)

Date:__________ Equipment # : ______________	Setup	Productive	Maintenance	Idle	Standby	Comments
0800-0900						
0900-1000						
1000-1100						
1100-1200						
1200-1300						
1300-1400						
1400-1500						
1500-1600						

Table 7.1 Equipment Use Data collection form

This data collection form is presented as an example of a potential method for obtaining equipment utilization information. The equipment utilization data provided for this thesis were collected from distribution of a survey (Appendix B) and did not incorporate use of the time sheet shown in Table 7.1.

2. Time Frame of Analysis

The time frame of analysis for this type of information is an important consideration. Research and development laboratories perform many different tasks, and equipment use is driven by sponsor funded projects and overall mission objectives. RDT&E projects are cyclical and have no standard duration. To compare utilization rates on a daily or weekly basis would be misleading. An appropriate time frame of analysis that captures several cycles of activity, based on management experience and knowledge of variable project length and cycle time, is three years worth of data (Harris, 1998). This

type of historical equipment utilization data is not available under the present system. As a result, the questionnaire in Appendix B was used to gather data from laboratory operators and managers approximating equipment utilization for Fiscal Year 1997. The results were used as input to the CAM-I Capacity model and are presented later in this chapter. The reports generated from these data are intended to demonstrate model attributes and provide management with insight into the analysis and decision-making tools available for measuring capacity utilization. However, given the data collection process, the examples in this thesis may not represent actual utilization rates experienced in Fiscal Year 1997.

B. DATA SOURCES FOR AIRCREW SYSTEMS (4.6) LABORATORIES

Input for the models and measures presented in this section were gathered from Aircrew Systems (4.6) laboratory data collected from NAWCAD accounting records, an independent database of laboratory information, interviews, observations, and a questionnaire distributed to laboratory managers. The two areas studied, productivity and capacity utilization, are each supported by different types of research data. The productivity measures presented in this chapter use historical data collected from accounting records for FY 1997 and estimates of performance for FY 1998 and 1999. Additionally, interviews with the Aircrew Systems (4.6) laboratories general manager (Harris, 1998) and Comptroller (Runion, 1998) provided supplemental information about future allocation of facility production overhead costs and general and administrative

costs not presently included in the NWCF FY 1997 laboratory rate calculations. The specific CAM-I capacity model examples of capacity utilization presented in this chapter use data collected from responses to the questionnaire shown in Appendix B, as well as cost data supplied by NAWCAD and the independent database. Details of the data collection methods used are presented in the following sections.

1. Capacity Utilization

Observation of laboratory activity and interviews with Aircrew Systems (4.6) laboratory managers and facility supervisors were conducted, providing the background information necessary to develop the questionnaire (Harris, 1998). The questionnaire asked laboratory managers to estimate equipment utilization rates experienced in FY 1997. It also prompted respondents to identify laboratories by types of RDT&E activity, facilities, and equipment. The data collected from the questionnaire are based on laboratory managers' experience and judgement of actual FY 1997 activity. Presentation of this data in the CAM-I Capacity model is intended to provide management with an example of the model's ability to communicate utilization information. The accuracy of the information depends on the ability of the managers to recall actual usage.

The responses include all nine of the Aircrew Systems (4.6) Level II groups of laboratories. Each of the Aircrew Systems (4.6) managers with Level II responsibility estimated equipment utilization rates based on an aggregate of laboratory activity reported by the appropriate individual Level III laboratories.

Each level represents a different organizational focus of analysis for capacity utilization information. Recent studies such as the 1997 Quadrennial Defense Review and Joint Vision 21 have emphasized that DOD RDT&E activities needed to standardize accounting and reporting formats. As a result, NAWCAD has established Level II as its standard baseline for reporting RDT&E laboratory activity (Collier, 1998). Accordingly, the present NAWCAD RDT&E financial management system is designed to capture accounting data at the Level II organizational level. Adaptation of full cost accounting procedures and an activity based accounting system in the future may facilitate more detailed accounting and reporting of laboratory activity at lower levels of the organization, i.e. Level III laboratories (Collier, 1998). The CAM-I model examples in this thesis represent information for Level II laboratory activity.

2. Productivity

FY 1997 historical cost and revenue data were obtained from sources both internal and external to the organization. Eagan McAllister Associates, Inc. (EMA), a defense contractor, has been working closely with NAWCAD facilities management to help design productivity measures for the Research and Engineering (4.0) laboratories (Collier, 1998). A database was established, including a description of activities, cost, revenue, and square footage of space allocated to each laboratory. The EMA database is the primary source of direct laboratory costs and revenues used in this thesis. Indirect costs of production overhead, utilities and general and administrative were not included

in the EMA database. Capturing the full cost of RDT&E activity requires both direct and indirect cost identification. As a result, additional accounting data were collected from the NAWCAD Comptroller's office, which identified Research and Engineering (4.0) laboratory production overhead and general and administrative costs. Combining the direct costs from the EMA database with the indirect costs applicable to Aircrew Systems (4.6) laboratories allows for an approximation of full costs for Aircrew Systems (4.6) laboratory activities to be input into productivity measures presented in this Chapter.

Projected FY 1998 and 1999 cost and revenue figures were gathered from budget estimates provided by Aircrew Systems (4.6) laboratory managers. The estimates represent laboratory activity anticipated from future DOD sponsored projects and potential non-DOD contract business. Use of these data provides a multi-year view of actual and estimated cost and revenue distribution, reducing the effect of short-term variability in laboratory activity on overall productivity. These cost and revenue data were used as input into the productivity measures described in this chapter to provide examples of the types of productivity tools available to NAWCAD managers.

C. CAM-I CAPACITY MODEL PRESENTATION OF AIRCREW SYSTEMS (4.6) LABORATORY EQUIPMENT UTILIZATION DATA

Equipment utilization data for the CAM-I capacity model examples presented in this section were collected from the questionnaire shown in Appendix B. A summary of responses to questions about equipment utilization is presented in tabular form in Table 7.2.

Level II Aircrew Systems (4.6) Lab Title	Equipment Utilization								
	Productive			*Non-Productive*			*Idle*		
	Good Products	Product Dev.	Process Dev.	Set Up	Maint.	Standby	Restricted	Marketable	Not Marketable
Advanced Crewstation Technology (CTL) Lab	60%	5%	15%	0%	15%	0%	0%	5%	0%
Aircraft Integration/Test Labs	53%	5%	11%	1%	6%	9%	0%	16%	0%
Aircrew Altitude Protection & Breathing System Facility	78%	3%	5%	1%	4%	3%	0%	8%	0%
Aircrew Protection and Survival Equipment RDT&E	80%	5%	0%	10%	5%	0%	0%	0%	0%
Crashworthy System RDT&E Facility	80%	4%	6%	6%	4%	0%	0%	0%	0%
Crew Systems Integration Lab	70%	0%	15%	0%	15%	0%	0%	0%	0%
Crewstation Transparency and Lighting Lab	70%	0%	15%	0%	15%	0%	0%	0%	0%
Escape System RDT&E Lab Facility	72%	3%	10%	10%	5%	0%	0%	0%	0%
Thermophysiology Research Facility	60%	5%	0%	5%	5%	0%	0%	25%	0%
Total Aircrew Systems (4.6) Laboratories:	69%	3%	9%	4%	8%	1%	0%	6%	0%

Table 7.2 Aircrew Systems (4.6) Laboratory Equipment Utilization Data

Equipment utilization rates are represented for each of the nine Aircrew Systems (4.6) Level II laboratory groups. The data presented in table 7.2 were used to construct CAM-I capacity model templates as examples of Aircrew Systems (4.6) capacity utilization. Totals for all of Aircrew Systems (4.6) laboratories are calculated by averaging the results of the nine individual Level II responses. The totals represent overall Level I Aircrew Systems (4.6) equipment capacity utilization.

Additional data describing laboratory characteristics were collected from the questionnaire and are presented in Table 7.3. Each laboratory is categorized by facility type, equipment type, and function. This information provides the framework from which comparisons of performance can be made among laboratories with similar characteristics. For example, laboratories primarily using large mechanical equipment in a high bay mechanical facility may exhibit cost and activity behavior significantly different than laboratories primarily using small technical equipment in a raised floor computer and electronics facility. Separate benchmarks of performance for laboratories with similar characteristics may provide better decision-making information to managers.

Level II Aircrew Systems (4.6) Lab Title	LABORATORY CHARACTERISTICS										
	Facility Type			Function					Equipment Type		
	M	C	G	Production	R&D	Certification	In-Service	SSA	L	T	N
Advanced Crewstation Technology (CTL) Lab		C		0%	80%	20%	0%	0%		T	
Aircraft Integration/Test Labs			G	14%	80%	0%	0%	0%		T	
Aircrew Altitude Protection & Breathing System Facility			G	1%	57%	13%	30%	0%		T	
Aircrew Protection and Survival Equipment RDT&E			G	5%	55%	0%	40%	0%		T	
Crashworthy System RDT&E Facility	M			0%	65%	30%	5%	0%	L		
Crew Systems Integration Lab		C		0%	45%	50%	5%	0%		T	
Crewstation Transparency and Lighting Lab		C		0%	45%	50%	5%	0%		T	
Escape System RDT&E Lab Facility	M			0%	40%	30%	30%	0%	L		
Thermophysiology Research Facility	M			0%	100%	0%	0%	0%	L		
Total Aircrew Systems (4.6) Laboratories:				2%	63%	22%	13%	0%			

Facility Type:		Equipment Type:	
	M = High Bay Mechanical		L = Large Mechanical
	C = Computer & Electronics		T = Technical
	G = General Purpose Clean Lab		N = Non-Technical

Table 7.3 Aircrew Systems (4.6) Laboratory Characteristics

Using the data from table 7.2, examples of the CAM-I basic time template shown in Figure 7.1 were constructed for the following Level II laboratories: Advanced Crewstation Technology Lab, Aircraft Integration/Test Labs, and Thermophysiology Research Facility. These Level II laboratories were chosen as examples to demonstrate the CAM-I model's ability to communicate and highlight capacity utilization across a diverse spectrum of laboratory types.

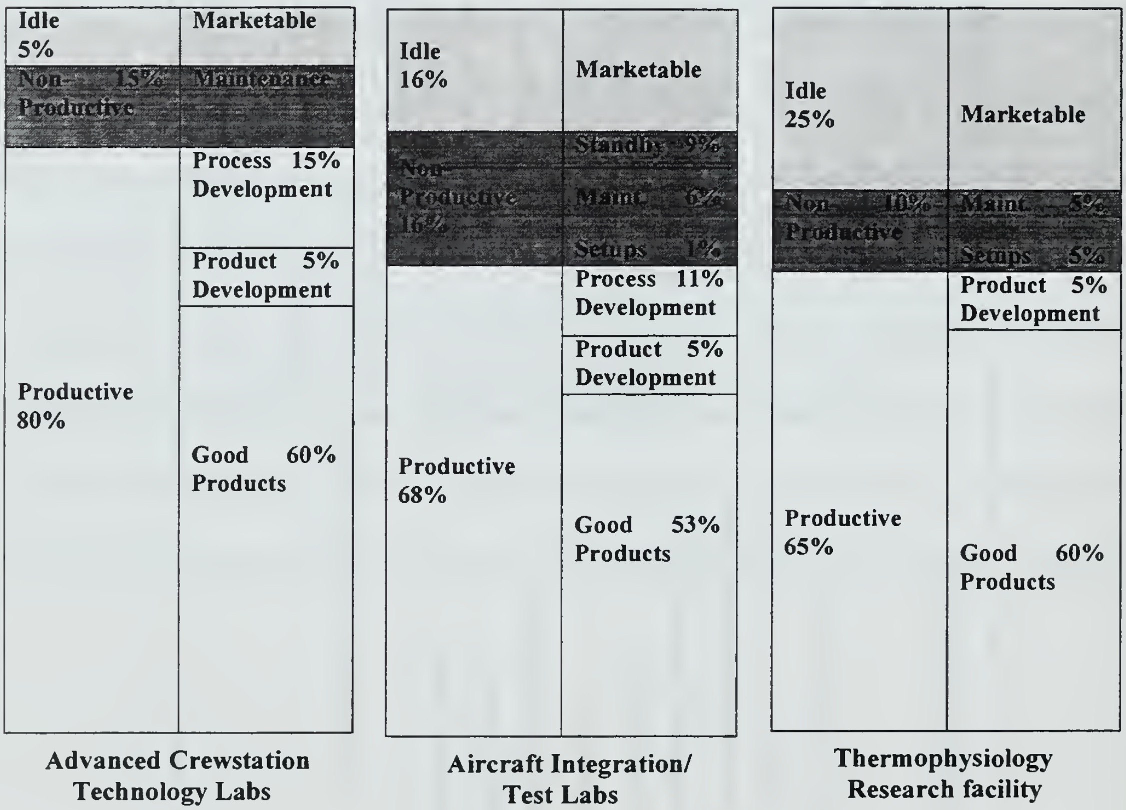

Figure 7.1 CAM-I Basic Time Templates for Aircrew Systems Level II laboratories

Each of the examples in Figure 7.1 represents a different type of laboratory facility. The Advanced Crewstation Technology Labs primarily operate in computer and electronics facilities, the Aircraft Integration/Test Labs primarily operate in general purpose clean lab facilities, and the Thermophysiology Research Facility is a high bay mechanical facility. The different states of capacity, idle, productive, and non-productive are identified as a percent of total rated capacity. In the NAWCAD adjusted CAM-I model, total rated capacity represents eight hours a day, 5 days a week. This information can also be presented as units of time, i.e. hours and minutes. For instance, 25 percent of total rated capacity represents two hours of time out of the eight hours available per day.

Figure 7.1 illustrates the amount of time that capacity is in an idle state for each of the laboratories. The Thermophysiology Research Facility reported that one quarter of the total capacity available is idle and marketable. In contrast, the Advanced Crewstation Technology Labs reported only five-percent idle capacity. Idle, marketable capacity represents additional business opportunity. It also highlights areas of potentially underutilized capacity. Laboratories with high levels of idle capacity are tying up resources that may be better utilized by other laboratories constrained by capacity limits. This type of analysis is relevant for space allocation and capital investment decision-making.

The examples also provide insight into the types of non-productive and productive capacity used. Identifying non-productive time classified as standby for the Aircraft Integration/Test Labs highlights potential inefficiencies in scheduling or material

handling and supply systems. A comparison of productive capacity among the three examples draws attention to the process development component of the Advanced Crewstation Technology Labs capacity utilization. Process improvement and development may be critical to the successful operation of the laboratory; however, it does not directly produce output for the customer and is not included in the utilization measure defined as project funded laboratory activity or "good products". Acquiring project funding and producing good products for the customer are essential to successful NAWCAD laboratory operations. Maximizing project funded laboratory activity can only occur if idle and non-productive capacity utilization is minimized.

The differences in facility type, along with other laboratory characteristics, may explain some of the variance in capacity utilization among laboratories. Table 7.3 lists each Level II laboratory by operating characteristics of facility type, equipment type, and functions performed. Categorizing laboratories by their operating characteristics, and comparing performance among similar types of laboratories, may provide a more relevant baseline of comparison. The data in Table 7.3 are used later in this chapter to establish specific categories of laboratories from which benchmarks of performance are determined.

The capacity information conveyed by the basic time template (Figure 7.1) relies on information about capacity utilization from the operational level. This presentation format allows for identification and communication of capacity use among Level II

laboratory groups. The next step is to translate the operational time data into financial information useful for economic decision-making at all levels of the organization.

Applying laboratory costs to the different types of capacity use provides the basic economic template for each of the laboratory groups. Direct and indirect costs are combined to represent a full cost approach. Direct costs include those for labor, engineering support, spares, maintenance, contracts, consumables, utilities, and training. The indirect costs added are production overhead and general and administrative. Table 7.4 displays Aircrew Systems (4.6) Level II laboratory costs for FY 1997.

LEVEL II LABORATORY TITLE	Direct Costs (K$)	Prod Ovhd (K$)	G & A (K$)	Total (Full Cost) (K$)
Advanced Crewstation Technology Lab	$1702	$182	$624	$2,508
Aircraft Integration/Test Labs	$290	$234	$241	$766
Aircrew Altitude Protection & Breathing	$336	$114	$303	$754
Aircrew Protection and Survival Equipment	$290	$351	$321	$962
Crashworthy System RDT&E Facility	$626	$186	$267	$1,081
Crew Systems Integration Lab	$1332	$38	$401	$1,771
Crewstation Transparency and Lighting Lab	$282	$72	$499	$854
Escape System RDT&E Lab Facility	$433	$122	$441	$996
Thermophysiology Research Facility	$109	$177	$71	$358
TOTAL Aircrew Systems	**$5400**	**$1477**	**$3100**	**$10,050**

Table 7.4 FY 1997 Aircrew Systems (4.6) Level II Laboratory Costs

CAM-I economic templates, shown in Figure 7.2, communicate the results of distributing the FY 1997 costs to idle, non-productive, and productive states of capacity.

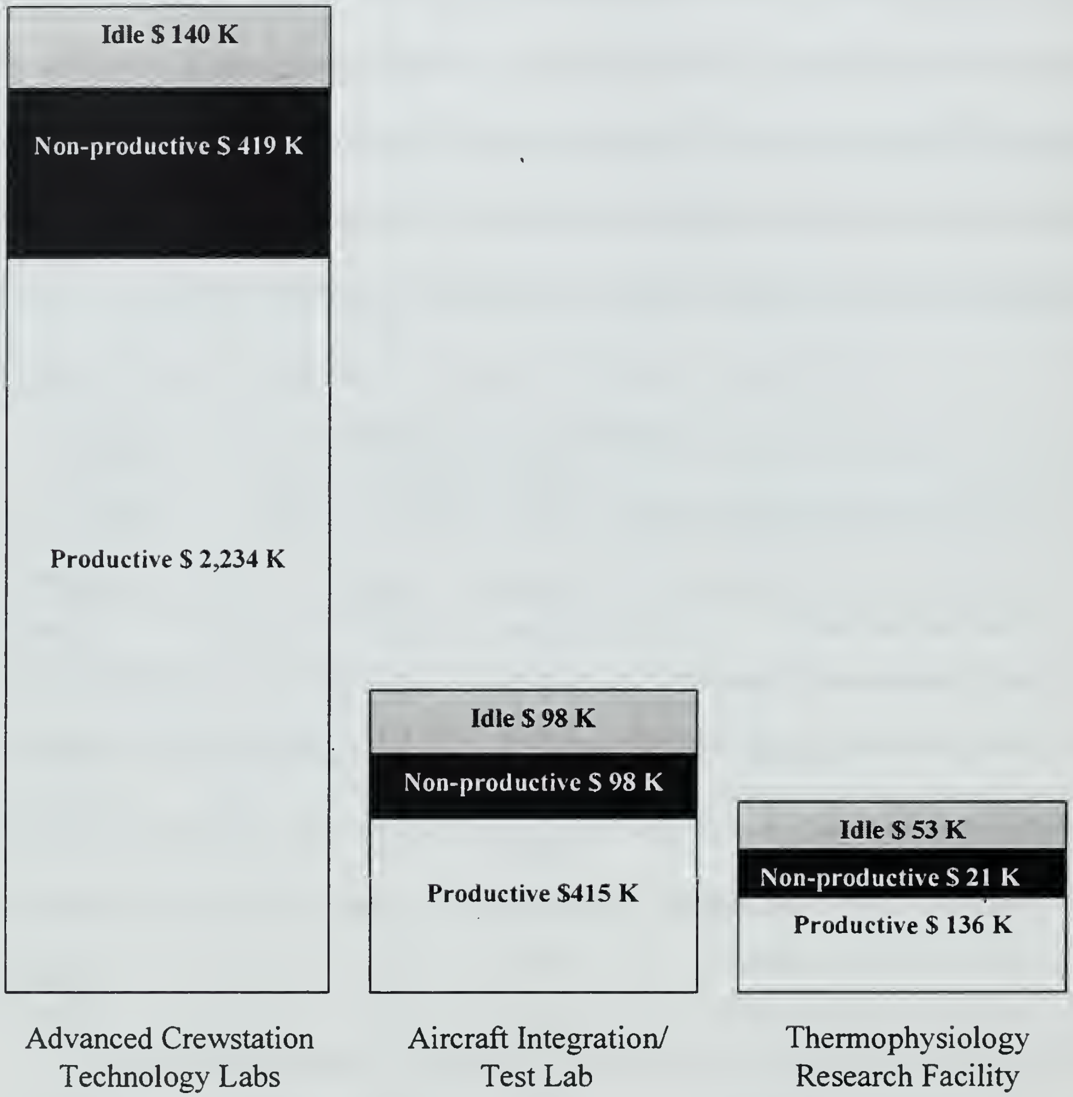

Figure 7.2 CAM-I Economic Templates for Aircrew Systems (4.6) Level II Laboratories

Unlike the time template, where equal time exists for each capacity set, the basic economic template for each increment of capacity differs. Another characteristic of the economic template is that the cost for time in idle capacity is usually less than an equal amount of time in a productive state (Klammer, 1996). This occurs due to the reduced personnel and maintenance requirements associated with idle activity. With an activity based costing system in place, identifying costs for each state of capacity should be a logical extension of the accounting process. Until ABC systems are implemented for NAWCAD, allocation of costs to the different states of capacity should be determined by facility and financial managers. The examples presented in Figure 7.2 distribute costs to the different states of capacity in direct proportion with the amount of time assigned.

The capacity information conveyed by the economic templates provides managers with financial data for economic analysis and decision-making. A summary model for all of the Aircrew Systems (4.6) laboratories is shown in Figure 7.3. This Level I summary model is an example of the CAM-I model's ability to communicate capacity utilization information to different levels of the organization. Upper level management may be interested in reviewing total Level I capacity figures as shown in Figure 7.3, while Level II and Level III templates can be produced to provide operational level managers with more detail.

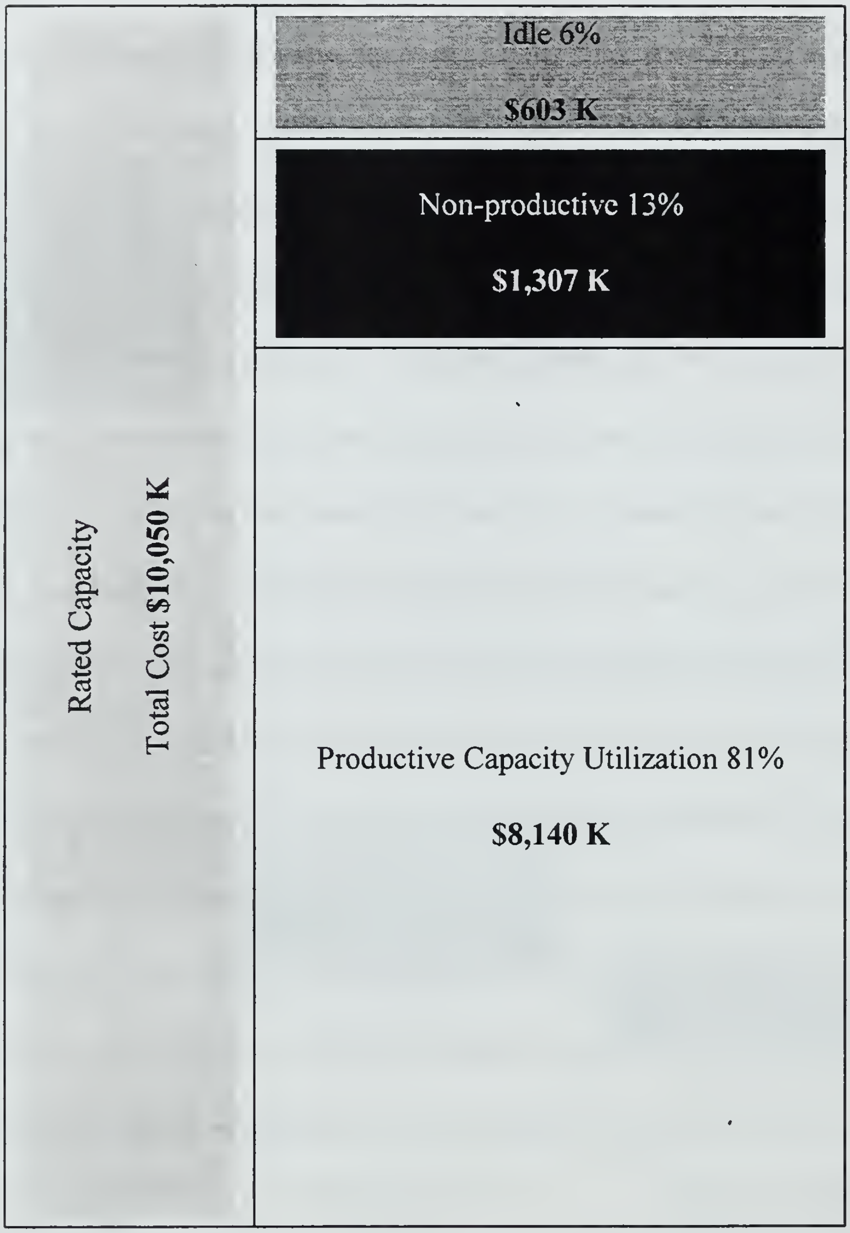

Figure 7.3 Aircrew Systems (4.6) Level I CAM-I Summary Model

D. AIRCREW SYSTEMS (4.6) LABORATORY PRODUCTIVITY DATA PRESENTATION

The laboratory cost, revenue, and square footage data used for productivity measures presented in this section were collected from FY 1997 NAWCAD accounting records and budget projections for FY's 1998 and 1999, as well as selected data from the Aircrew Systems (4.6) database developed and maintained by Egan Mcallister and Associates, Inc. Examples of Return on Operations Index (ROOI) and Operating Margin calculations are presented as measures of productivity for the Level II laboratories. Cost, revenue, and operating margin per square foot of facility space allocated are also presented providing managers additional financial tools for space allocation and capital investment decision-making.

1. Return on Operations Index (ROOI)

The ROOI compares laboratory revenue against all costs associated with laboratory activity. The equation used to calculate ROOI is:

Return on Operations Index (ROOI) = Total Revenue / Total Cost of Operations

Aircrew Systems (4.6) Level II laboratory cost figures for FY 1997 and projected costs for FY 1998 and 1999 are shown in Table 7.5. The FY 1997 cost figures are taken from Table 7.4, while the projected costs for FY 1998 and 1999 are budget estimates provided by laboratory managers. Production overhead and general and administrative costs for FY 1998 and 1999 were allocated based on budgeted levels of activity.

Level II Laboratory Title	97 Actual Cost (K$)	98 Projected Cost (K$)	99 Projected Cost (K$)	3-Yr Avg Annual Cost (K$)
Advanced Crewstation Technology Lab	$2,508	$2,990	$2,695	$2,731
Aircraft Integration/Test Labs	$766	$999	$981	$915
Aircrew Altitude Protection & Breathing	$754	$821	$827	$800
Aircrew Protection and Survival Equipment	$962	$1,327	$1,744	$1,344
Crashworthy System RDT&E Facility	$1,081	$2,673	$2,339	$2,031
Crew Systems Integration Lab	$1,771	$1,232	$1,269	$1,424
Crewstation Transparency and Lighting Lab	$854	$1,122	$1,227	$1,068
Escape System RDT&E Lab Facility	$996	$1,884	$1,892	$1,591
Thermophysiology Research Facility	$358	$1,333	$1,465	$1,052
TOTAL Aircrew Systems	**$10,050**	**$14,381**	**$14,439**	**$12,956**

Table 7.5 Aircrew Systems (4.6) Level II Laboratory Costs

Revenue figures for FY 1997, along with projections for FY 1998 and FY 1999 are shown in Table 7.6. A comparison of the full cost and revenue data for Aircrew Systems (4.6) Level II laboratories for FY 1997 is represented in Figures 7.4 and 7.5. These data are used in the following section to demonstrate productivity measures such as ROOI, operating margin, and operating margin per square foot.

Level II Laboratory Title	97 Actual Revenue (K$)	98 Projected Revenue (K$)	99 Projected Revenue (K$)	3-Yr Avg Annual Revenue (K$)
Advanced Crewstation Technology Lab	$7,270	$7,596	$3,597	$6,154
Aircraft Integration/Test Labs	$2,071	$1,246	$1,220	$1,512
Aircrew Altitude Protection & Breathing	$1,855	$1,783	$1,829	$1,822
Aircrew Protection and Survival Equipment	$2,148	$3,513	$2,756	$2,806
Crashworthy System RDT&E Facility	$1,827	$3,261	$2,854	$2,647
Crew Systems Integration Lab	$3,194	$2,549	$2,605	$2,783
Crewstation Transparency and Lighting Lab	$710	$525	$522	$586
Escape System RDT&E Lab Facility	$2,526	$2,787	$2,757	$2,690
Thermophysiology Research Facility	$1,220	$2,016	$2,016	$1,751
TOTAL Aircrew Systems	**$22,820**	**$25,275**	**$20,156**	**$22,750**

Table 7.6 Aircrew Systems (4.6) Level II Laboratory Revenue

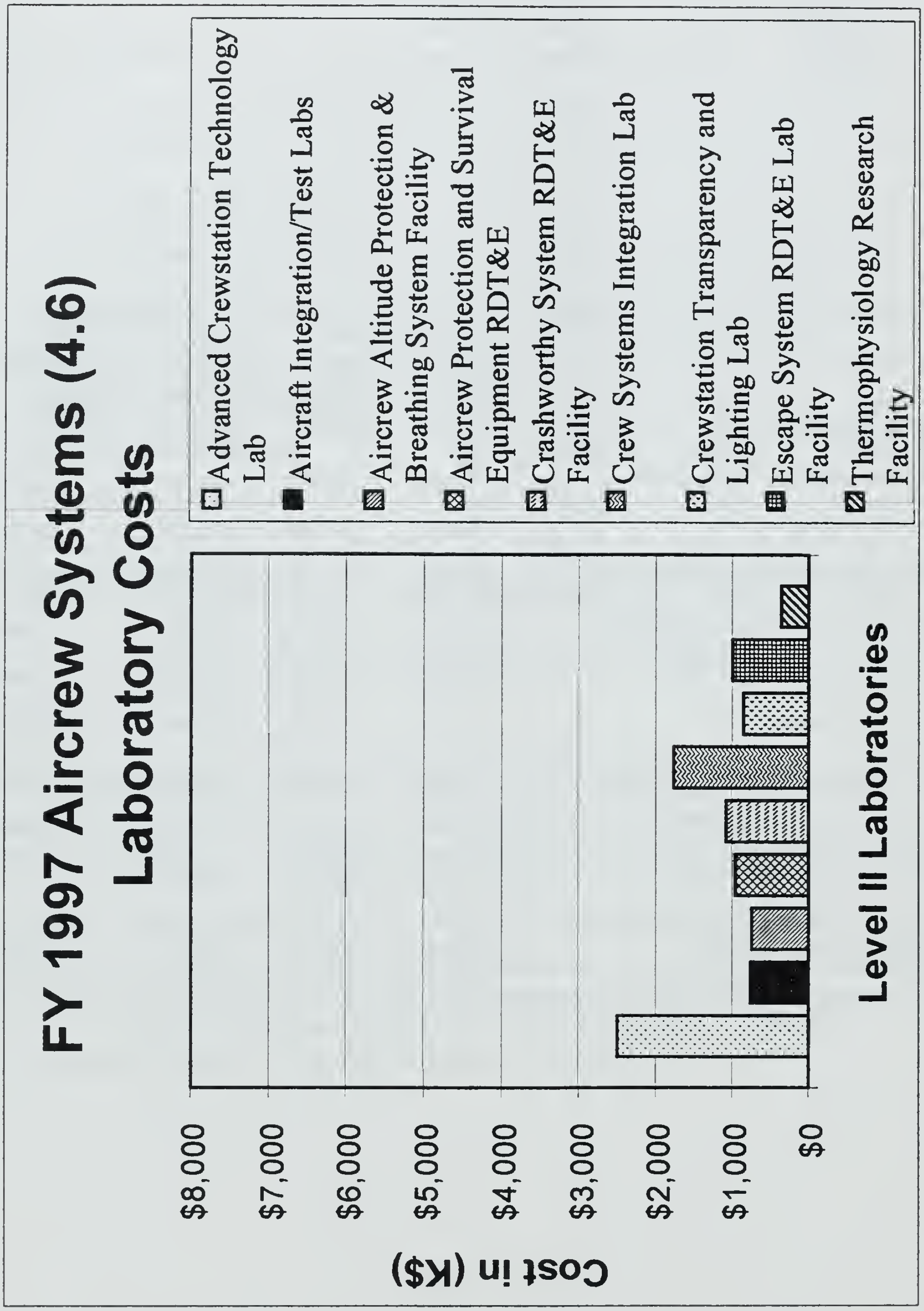

Figure 7.4 FY 1997 Aircrew Systems (4.6) Laboratory Costs

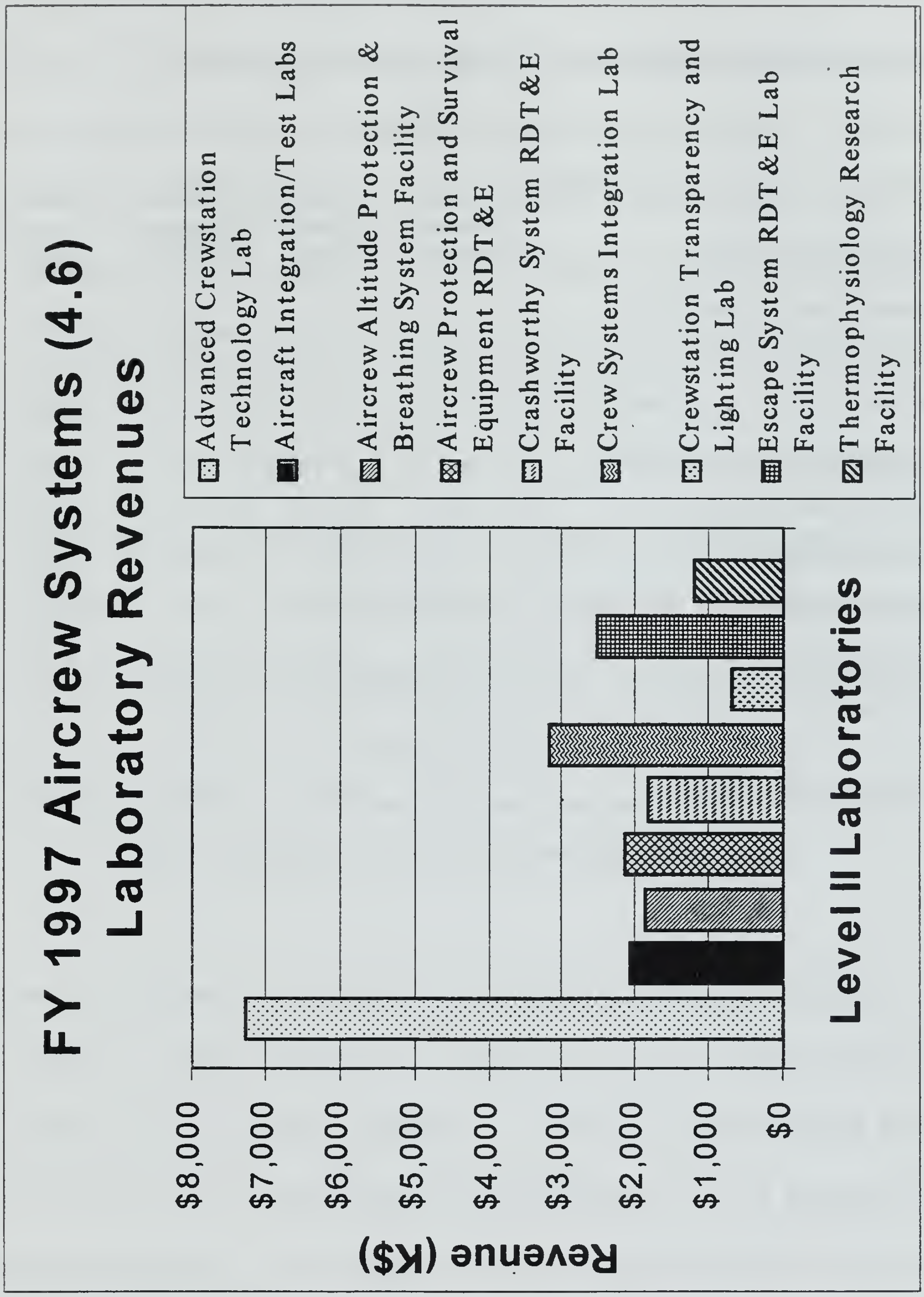

Figure 7.5 FY 1997 Aircrew Systems (4.6) Laboratory Revenues

The ROOI for each of the Level II laboratory groups was calculated using the cost and revenue data from Tables 7.5 and 7.6 and is presented in Table 7.7.

Level II Laboratory Title	97 Actual ROOI	98 Projected ROOI	99 Projected ROOI	3-Yr Average ROOI
Advanced Crewstation Technology Lab	2.90	2.54	1.33	2.25
Aircraft Integration/Test Labs	2.70	1.25	1.24	1.65
Aircrew Altitude Protection & Breathing	2.46	2.17	2.21	2.28
Aircrew Protection and Survival Equipment	2.23	2.65	1.58	2.09
Crashworthy System RDT&E Facility	1.69	1.22	1.22	1.30
Crew Systems Integration Lab	1.80	2.07	2.05	1.95
Crewstation Transparency and Lighting Lab	0.83	0.47	0.43	0.55
Escape System RDT&E Lab Facility	2.54	1.48	1.46	1.69
Thermophysiology Research Facility	3.41	1.51	1.38	1.66
TOTAL Aircrew Systems	**2.27**	**1.76**	**1.40**	**1.76**

Table 7.7 Aircrew Systems (4.6) Level II Laboratory ROOI

An average ROOI for the three years of data (FY's 97, 98, and 99) is presented to demonstrate the affect of short-term variability in laboratory activity. Any single year data may be misleading as an indicator of long-term performance. For example, the ROOI calculated for the Thermophysiology Research facility for FY 1997 is 3.41; however the projected ROOI for the next two years is lower. The three year average ROOI of 1.66 is more representative of the laboratories overall performance.

An internal benchmark ROOI provides a baseline measure of laboratory performance. Laboratories of similar function or operating characteristics may be grouped together to establish comparable standards of performance. As discussed previously, the desired time frame of analysis is three years worth of data. In the absence of three years of historical data for the Aircrew Systems (4.6) laboratories, a combination of 1997 historic data and 1998-99 projected figures were used as an example of a three-year laboratory activity cycle. The Aircrew Systems (4.6) laboratories three-year average ROOI of 1.76 shown in Table 7.7 can potentially be used as a benchmark for the group. Individual laboratory ROOI, compared with the benchmark ROOI for that group, gives management a method for evaluating laboratory productivity. The example shown in Figure 7.6 compares laboratories against an Aircrew Systems (4.6) benchmark ROOI of 1.76.

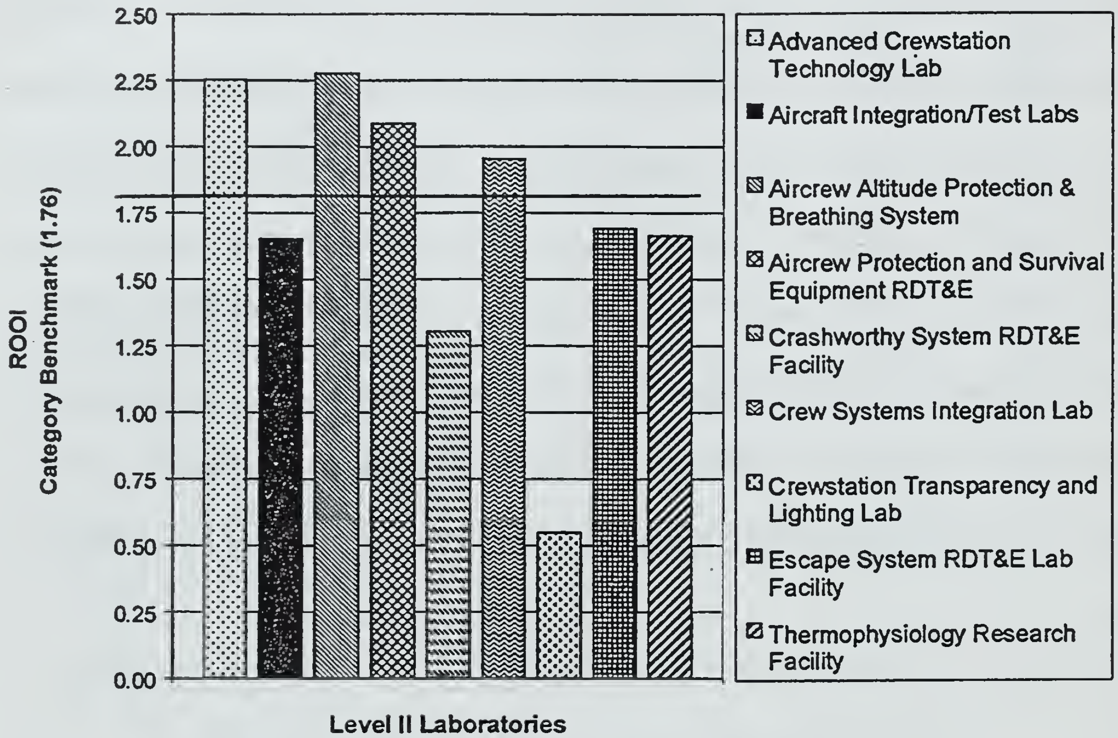

Figure 7.6 Aircrew Systems (4.6) Benchmark ROOI Comparison

Categorizing the Level II laboratories by facility type and determining a separate benchmark ROOI for each category provides more specific comparisons of performance as depicted in Table 7.8.

FACILITY TYPE ROOI BENCHMARK	
High Bay Mechanical	**ROOI**
Crashworthy Systems RDT&E Facility	1.30
Escape Systems RDT&E Lab Facility	1.69
Thermophysiology Research Facility	1.66
Category Benchmark	**1.55**
Computer and Electronics	
Advanced Crewstation Technology Lab	2.25
Crew Systems Integration Lab	1.95
Crewstation Transparency and Lighting Lab	0.55
Category Benchmark	**1.59**
General Purpose Clean Labs	
Aircraft Integration/Test Labs	1.65
Aircrew Altitude Protection & Breathing System Facility	2.28
Aircrew Protection and Survival Equipment RDT&E	2.09
Category Benchmark	**2.01**

Table 7.8 Aircrew Systems (4.6) Level II Laboratory Facility Type Benchmark ROOI

A closer look at the data reveals that the highest three-year average ROOI figure belongs to the laboratories categorized as general-purpose clean laboratories. The average ROOI for this category is 2.01. In contrast, the average ROOI for the computer and electronics laboratories is 1.59. This is one example of the type of categorization that

is available for management review. Management preferences and further research can help determine the most useful comparison categories.

2. Operating Margin

The operating margin for each laboratory is the difference between revenue and full cost. ROOI calculations discussed in the previous section describe laboratory cost and revenue relationships as a percentage, whereas operating margin represents the same relationship as a total dollar amount contributed to the organization as a whole. Table 7.9 lists the operating margin for Aircrew Systems (4.6) Level II laboratories for FY 1997 and projected operating margin amounts for FY 1998 and 1999 using the cost and revenue data from Tables 7.5 and 7.6.

There are differences in the dollar amount of operating margin provided by each of the Level II laboratories. The Advanced Crewstation Technology Lab contributed $4,761 K in FY 1997, while the Crewstation Transparency and Lighting Lab actually lost money and was a financial drain on the organization in the amount of $145K. Once again, a three-year look at the data provides a better indication of trends and overall long-term performance. In this case, the Advanced Crewstation Technology Lab remains the largest dollar contributor of the group for the three-year period; yet a trend of decreasing operating margins is projected for years 1998 and 1999. Increasingly negative operating margins are also projected for the Crewstation Transparency and Lighting Lab. This

operating margin analysis identifies financial strengths and weaknesses in terms of operational cash flow.

Level II Laboratory Title	97 Actual Operating Margin (K$)	98 Projected Operating Margin (K$)	99 Projected Operating Margin (K$)	3-Yr Avg Annual Operating Margin (K$)
Advanced Crewstation Technology Lab	$4,761	$4,605	$901	$3,423
Aircraft Integration/Test Labs	$1,305	$247	$239	$597
Aircrew Altitude Protection & Breathing	$1,101	$962	$1,002	$1,022
Aircrew Protection and Survival Equipment	$1,186	$2,186	$1,012	$1,462
Crashworthy System RDT&E Facility	$746	$588	$515	$616
Crew Systems Integration Lab	$1,423	$1,317	$1,336	$1,359
Crewstation Transparency and Lighting Lab	- $145	- $597	- $705	- $483
Escape System RDT&E Lab Facility	$1,530	$903	$865	$1,099
Thermophysiology Research Facility	$862	$683	$551	$699
TOTAL Aircrew Systems	**$12,771**	**$10,895**	**$5,717**	**$9,794**

Table 7.9 Aircrew Systems (4.6) Level II Laboratory Operating Margin

3. Productivity per Square Feet

Measuring cost, revenue, and operating margin per square foot of facility space allocated to each laboratory allows for a space utilization performance comparison. Table 7.10 lists the total number of square feet assigned to each of the Aircrew Systems (4.6) Level II laboratories and provides three-year average cost, revenue, and operating margin amounts per square foot. Comparing the operating margin (per square foot) of each Level

II laboratory shown in Table 7.10 with the total operating margin dollar amounts shown in Table 7.9 illustrates the different perspective that this type of analysis provides.

Although the Crew Systems Integration Lab average annual operating margin is $1,359 K, the third highest total for Aircrew Systems, its $990 operating margin (per square foot) was the highest productivity per square foot of all nine Level II laboratories. From a financial perspective, the Crew Systems Integration Lab utilizes its space more productively than the other Aircrew Systems Level II laboratories.

Level II Laboratory Title	Square Feet Assigned	3 Yr Avg Cost / per Square Foot	3 Yr Avg Revenue / per Square Foot	3 Yr Avg Operating Margin / per Square Foot
Advanced Crewstation Technology Lab	6,623	$412	$929	$517
Aircraft Integration/Test Labs	8,519	$107	$178	$71
Aircrew Altitude Protection & Breathing	4,143	$193	$440	$247
Aircrew Protection and Survival Equipment	12,756	$105	$220	$115
Crashworthy System RDT&E Facility	6,768	$300	$391	$91
Crew Systems Integration Lab	1,373	$1,037	$2,027	$990
Crewstation Transparency and Lighting Lab	2,616	$408	$224	- $184
Escape System RDT&E Lab Facility	4,425	$359	$608	$249
Thermophysiology Research Facility	6,438	$163	$272	$109
TOTAL Aircrew Systems	**53,661**	**$241**	**$424**	**$183**

Table 7.10 Aircrew Systems (4.6) Level II Laboratory Productivity (per square foot)

E. AIRCREW SYSTEMS (4.6) LABORATORY PERFORMANCE COMPARISON CHART

Examples of capacity utilization and productivity measures have been demonstrated separately in the previous sections. The performance comparison chart incorporates the results of capacity utilization and productivity into a format that enables analysis across both dimensions of performance. Using the information from Table 7.2 and Table 7.7, a performance comparison chart is presented in Figure 7.7.

The chart displays the relative strengths and weaknesses of the three previously selected Level II laboratory examples. The X-axis represents the percent of rated capacity that has been identified as idle. The Y-axis is the ROOI calculated for each Level II laboratory. The lighter shaded area in the upper right portion of the chart indicates strength in both productivity (ROOI) and capacity utilization (low idle capacity). The dark shaded lower left portion of the chart indicates potential weakness across both dimensions of performance. From the chart, the user can determine the relative performance strengths and weaknesses among the three laboratories. The Advanced Crewstation Technology Lab displays strong productivity and capacity utilization relative to the other two laboratories. Each of the other two laboratories has similar productivity with varying levels of capacity utilization. Capacity utilization for the Thermophysiology Research Facility is the weakest of the three, yet the laboratory is maintaining an ROOI of over 1.5.

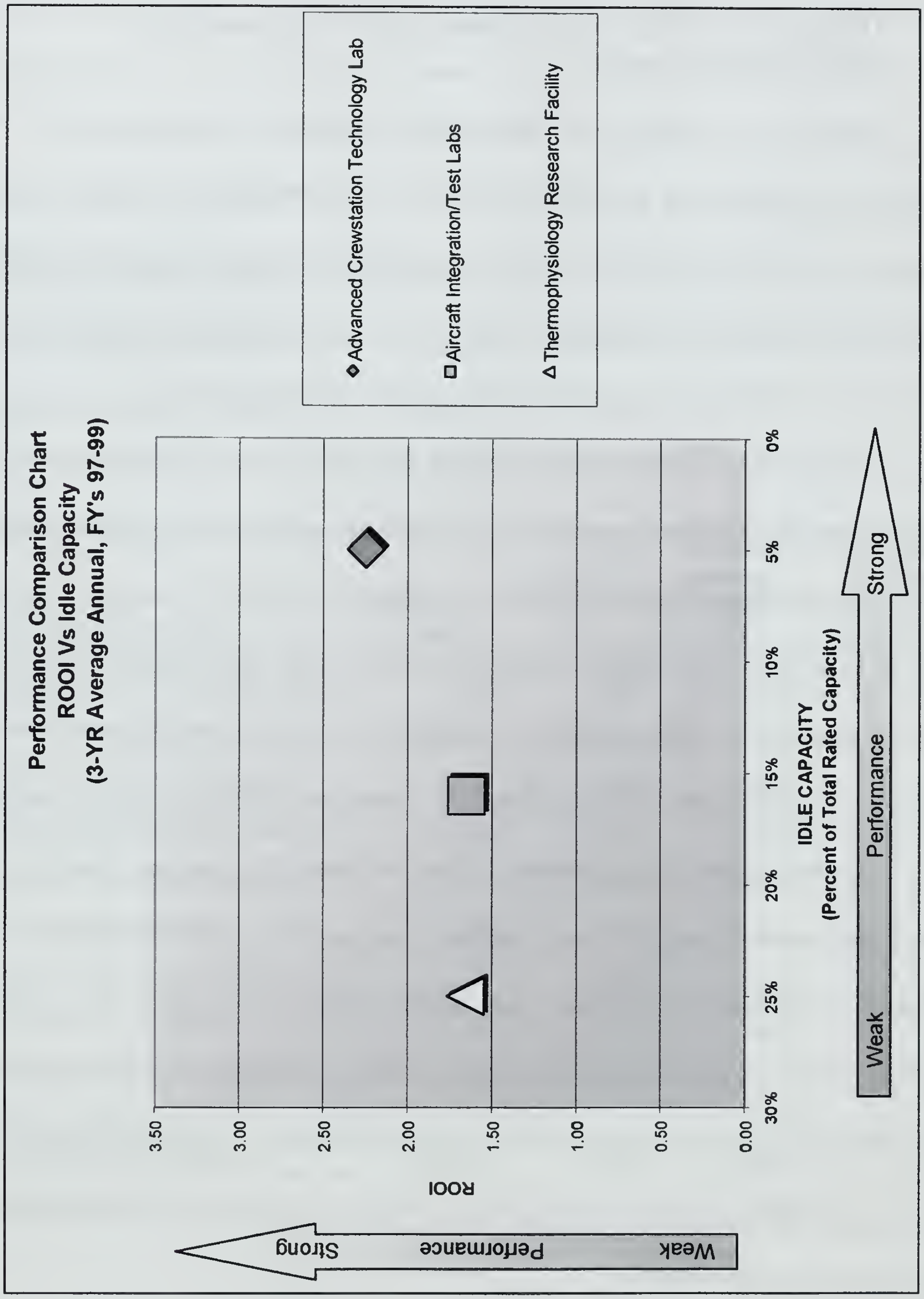

Figure 7.7 Aircrew Systems (4.6) Laboratory Performance Comparison Chart
ROOI Vs Idle Capacity

The chart illustrates that the three laboratories in Figure 7.7 are financially productive given their reported levels of capacity utilization but opportunities for improvement in both dimensions of performance are identified. For example, a decrease in idle capacity for the Thermophysiology Research Facility should result in more efficient utilization of laboratory resources. An associated increase in laboratory productivity may result in a higher level of productivity as measured by ROOI. Improvement in both dimensions of performance will move the laboratory up and to the right on the performance comparison chart.

A comparison of all Aircrew Systems (4.6) Level II laboratories is presented in Figure 7.8. In this performance comparison chart example, ROOI is the measure of productivity and productive capacity as a percent of total rated capacity is the measure of capacity utilization. The orientation of the chart is from lower left to upper right along a spectrum of weak performance to strong performance. The chart allows management to identify and compare all nine Aircrew Systems (4.6) Level II laboratories across both dimensions of performance. The Crewstation Transparency and Lighting Lab stands out as a low productivity laboratory relative to other (4.6) laboratories, while the Aircraft Integration/Test Labs and Thermophysiology Research Facility display low relative levels of capacity utilization.

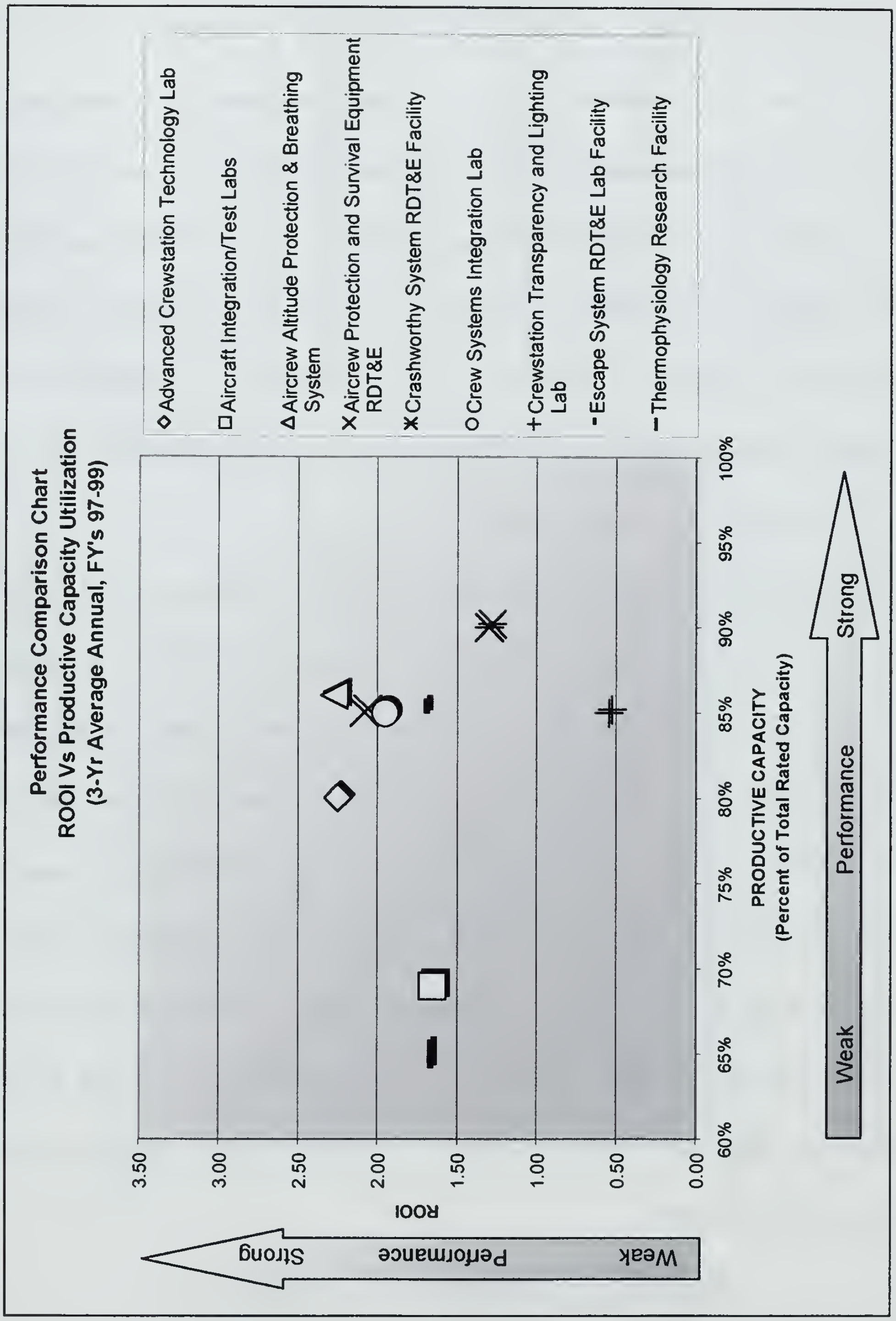

Figure 7.8 Aircrew Systems (4.6) Laboratory Performance Comparison Chart
ROOI Vs Productive Capacity

Different combinations of performance measures may be used to construct performance comparison charts that concentrate on specific business areas. For example, managers faced with space allocation decisions may use operating margin or operating margin per square foot as the financial productivity performance measure. Figure 7.9 plots the operating margin for each of the (4.6) Level II laboratories against productive capacity. Figure 7.10 represents a similar comparison, but the productivity measure of operating margin (per square foot) is used instead of total operating margin.

The differences are important to note and can affect the user analysis of laboratory performance. The two charts show similar results for most of the laboratories with one notable exception. The relative positions of the Advanced Crewstation Technology Lab and the Crew Systems Integration Lab are interchanged. Analysis of relative strengths and weaknesses of these two laboratories is different depending upon which measure is more relevant to the decision-making process. The chart identifies the Advanced Crewstation Technology Lab as the stronger performer if total dollar amount of operating margin is the preferred measure. The Crew Systems Integration Lab appears to be the stronger performer if operating margin (per square foot) is the preferred measure. Choosing which measures to use can impact the analysis of relative strengths and weaknesses as presented by the performance comparison chart.

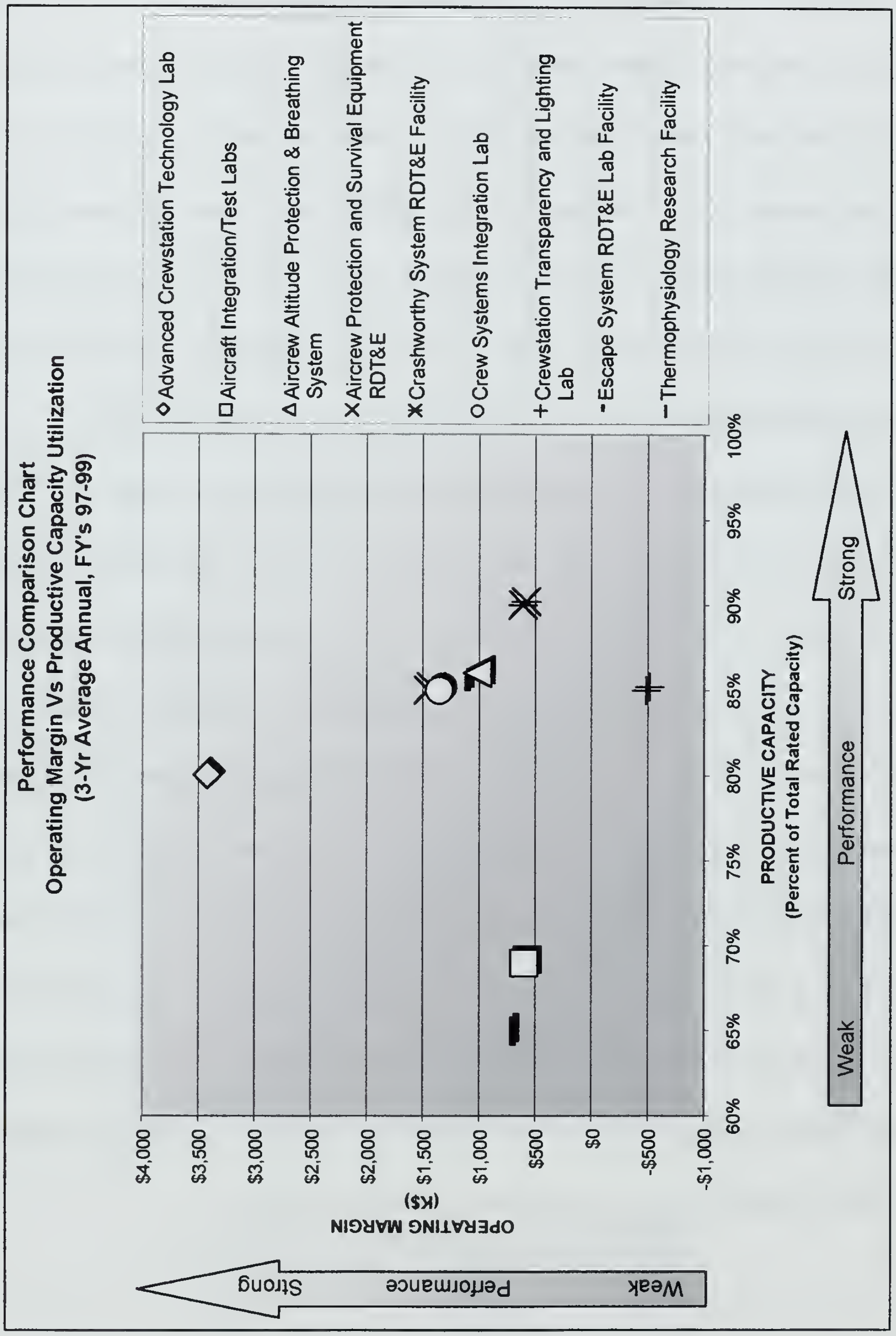

Figure 7.9 Aircrew Systems (4.6) Laboratory Performance Comparison Chart
Operating Margin Vs Productive Capacity

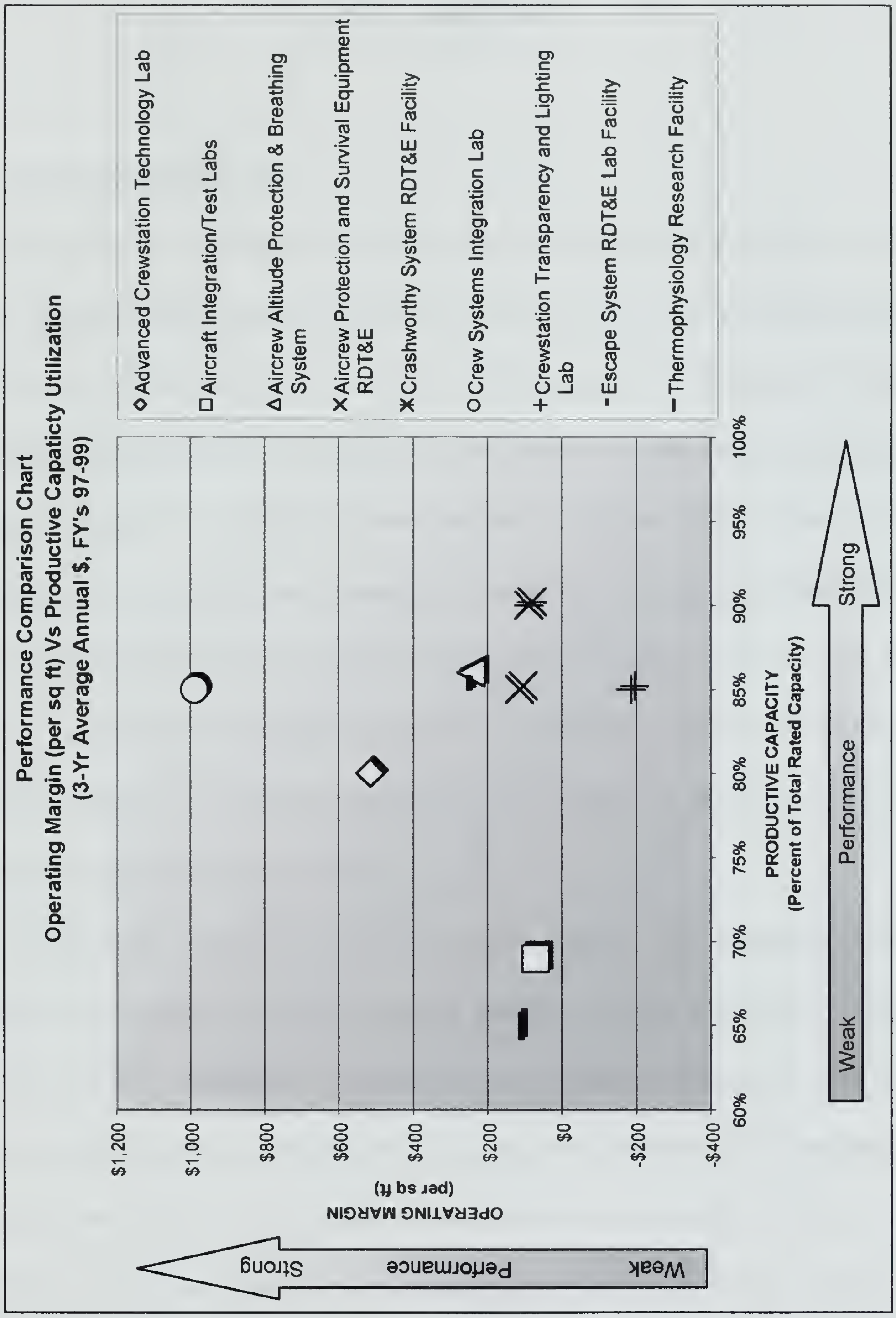

Figure 7.10 Aircrew Systems (4.6) Laboratory Performance Comparison Chart
Operating Margin (per square foot) Vs Productive Capacity

VIII. ANALYSIS

A. QUALITY OF DATA

The data for this thesis were collected from three primary sources, NAWCAD Aircrew Systems (4.6) laboratory accounting records for FY 1997, budget estimates for FY 1998 and 1999, and responses to the questionnaire shown in Appendix B. Examples of capacity utilization measures using the CAM-I capacity model incorporated laboratory manager estimates of FY 1997 equipment utilization. The accuracy of the estimates is dependent on the ability of the managers to recall the level of equipment utilization. However, their input into the CAM-I capacity model serves to illustrate the model's ability to convey capacity utilization information to the user. Additional observation and systematic reporting of equipment utilization is necessary to generate CAM-I model results for management decision-making.

Productivity measures of ROOI, operating margin, and operating margin per square foot incorporated historical accounting data for FY 1997 and budget estimates for FY 1998 and 1999. Production overhead and general and administrative costs included in the total cost figures were provided as an aggregate of all research and engineering 4.0 competency laboratories. Distribution of these indirect costs to each of the nine Level II laboratories studied was necessary to represent the full cost of each activity. The NAWCAD financial management system does not presently distribute these costs to the

individual Level II laboratories. Future allocation of indirect costs to NAWCAD RDT&E laboratories may differ from the allocation methods used in this thesis.

Analysis of laboratory performance, as indicated by the CAM-I capacity model and productivity measures developed for this research, should be performed using three years worth of data to reduce the effects of short term variability in laboratory activity on overall laboratory performance results (Harris, 1998). One year total cost and revenue figures used in Chapter VII as examples of FY 1997 laboratory productivity are representative of actual results but should not be considered a comprehensive evaluation of long term performance. Budget estimates for FY's 1998 and 1999, used as indicators of potential future performance, were included in the presentation of productivity measures to illustrate a multi-year analysis of data.

B. ASSESSMENT OF RESEARCH RESULTS

The CAM-I capacity model and productivity measures described in this thesis address NAWCAD RDT&E management objectives concerning the evaluation of laboratory performance. Each of the performance measurement techniques discussed is capable of measuring laboratory activity and reporting it in terms useful for financial analysis. Specific methods are defined, establishing two separate dimensions of performance, capacity utilization, and productivity. Each dimension provides management with unique information about laboratory performance. Combining the

results of the two dimensions of performance on a single performance comparison chart provides an overall perspective of laboratory financial strengths and weaknesses.

Comparison of results among laboratories facilitates informed decision-making in areas of capital investment, laboratory facility resource allocation, operational efficiency, and RDT&E infrastructure reduction. The application of these measures in the NAWCAD RDT&E laboratory environment was established through examples and analysis of Aircrew Systems (4.6) Level II laboratory data. The same methods applied to the Level II laboratories in this research are potentially applicable across all levels and types of DOD RDT&E activities.

1. Capacity Utilization

Using the CAM-I capacity model, capacity utilization information can be communicated to all levels of the organization. Different types of laboratory capacity utilization and their associated costs are identified using the reporting formats offered by the model. Accurate, comparable data are necessary for proper analysis. Comparison and analysis of laboratory capacity utilization data are available using the CAM-I basic time and economic template formats. With the planned development and implementation of activity based costing systems, collection of accurate, reliable cost data will be enhanced.

Application of the CAM-I capacity model to the NAWCAD RDT&E laboratory environment is not limited to any one measure of capacity utilization. Equipment

utilization measures described in this research represent one indicator of capacity utilization. Other viable methods of measuring laboratory capacity utilization may be incorporated into the model format. The ability to adapt to different operating environments is one of the primary reasons the CAM-I capacity model is a potential management tool for the NAWCAD RDT&E laboratories.

Additional measures of capacity such as utilization of personnel may be useful in providing a more comprehensive evaluation of utilization. Further research is required to determine the level of significance that equipment utilization rates have on overall capacity utilization. This research was conducted on the assumption that equipment utilization is a viable indicator of laboratory capacity utilization. However, the accuracy of equipment utilization data collected for this research has not been validated. The questionnaire used to collect equipment utilization data asked laboratory managers for estimates of FY 1997 equipment utilization based on experience and judgement. More systematic equipment utilization data collection methods should be administered to provide information for decision-making.

Data collection and analysis of laboratory activity was conducted at the Level II organizational level. The CAM-I model is capable of presenting utilization information at the level of detail desired by the user. Level III laboratory data may be required for in depth NAWCAD RDT&E financial activity analysis and decision-making. The NAWCAD financial management system in place does not presently account for Level III laboratory activity at the detail required for proper identification of individual

laboratory full costs. The Level II data collected in this thesis were therefore not able to identify individual Level III laboratory performance.

2. Productivity

The productivity measures of ROOI, operating margin, and operating margin per square foot focus on the relationship of revenues and costs associated with each laboratory. This approach applies financial accounting principles of full cost, net profit or loss, and operating profit margin to the NWCF account structure. Output for RDT&E laboratories is, therefore, defined in financial terms instead of units of physical product. Using a monetary measure of productivity allows for comparison of performance across a diverse range of activities. These measures can be applied to all RDT&E laboratories despite their operational and functional diversity.

Categorization of laboratories allows for comparisons of productivity among laboratories with similar operating characteristics. Different types of laboratories display operational characteristics which may be useful in establishing category benchmarks of performance. Three distinctive categories of laboratory facility type were used to compare performance against specific category benchmarks for the Aircrew Systems (4.6) Level II laboratories. The results indicate a potential relationship between facility type and productivity. A larger sample of laboratory data is required to further explore this relationship.

RDT&E facility space allocation and infrastructure reduction are issues of particular concern for NAWCAD RDT&E management. Operating margin per square foot of space allocated focuses management attention on the financial productivity of the space allocated to each laboratory. Examples of Aircrew Systems (4.6) Level II laboratory operating margin per square foot illustrate the relative productivity of facility space assigned to each of the laboratories. Similar comparisons can be established for other sets of laboratories. Management decision-making and review of laboratories competing for limited facility space should be enhanced with productivity information per square foot.

C. ADDITIONAL CONSIDERATIONS

1. Non-financial measures

All of the measures identified in this research are quantitative and comparable with a focus on the financial performance of RDT&E laboratories. Qualitative and non-financial measures of performance should be considered as part of any comprehensive performance analysis. Although a particular laboratory may indicate poor relative performance based on the measures discussed in this research, a review of non-financial factors may address strategic issues not captured in financial performance analysis. For example, some of the laboratory facilities owned by NAWCAD provide troubleshooting and technical support critical to fleet operations. Reduction of laboratory functions or resources based strictly on poor financial performance may jeopardize the fleet's ability

to operate necessary equipment and could essentially cripple mission readiness in the affected operational area.

Additionally, some of the laboratory facilities are considered national assets, which provide unique capabilities not available to DOD from other sources. The Aircrew Systems Ejection Seat Tower is an example of this type of facility. It is essentially the only one of its kind in the United States and is necessary for critical fleet ejection seat testing and troubleshooting. Specific criteria should be developed to evaluate if a laboratory is a critical asset as described above. Laboratories identified as critical NAWCAD RDT&E facilities should be noted in any analysis of performance. It is still useful to apply performance measures to these laboratories, but the additional non-financial information may be equally important in strategic decision-making.

2. Cost/Benefit

The costs associated with implementation of a NAWCAD capacity management system based on the CAM-I capacity model described in this thesis have not been determined. The level of effort dedicated to system design and implementation will be a determining factor of cost. NAWCAD has already obligated approximately two million dollars to contract for non-DOD expertise in initiating development of an activity based costing system and, specifically, to establish a database of RDT&E laboratory financial and operating characteristics (Collier, 1998). Similar efforts may be required to establish the CAM-I capacity model as a useful tool for NAWCAD RDT&E laboratories.

Productivity measures described in this thesis are a natural extension of activity based accounting system data and should incur minimal cost and effort for successful implementation.

The primary benefit of using the measures and tools presented in this research is better decision-making information. NAWCAD management is limited in its ability to compare competing laboratories when faced with facility space allocation and capital investment decisions (Collier, 1998). Accurate, timely collection and presentation of capacity utilization and productivity information can enhance the decision-making process, potentially improving long-term financial performance of NAWCAD RDT&E laboratories. The potential dollar savings expected from enabling better laboratory resource allocation decisions have not been determined. However, considering that NAWCAD research and engineering 4.0 competency laboratories requested twenty-seven million dollars for capital investment in FY 1997 and received only ten million (Collier, 1998), proper distribution of limited funds is dependent on the type of accurate, timely laboratory performance information that this research has described.

IX. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The emphasis on efficiency and sound business practices from a financial management perspective mandates that the Navy evaluate and incorporate appropriate performance measurement tools for RDT&E laboratories. Laboratory capacity utilization and productivity are primary indicators of performance. Put into terms useful for financial analysis, these tools should improve the quality of decision-making information available to the resource manager. This thesis has identified capacity utilization and productivity measures applicable to the NAWCAD RDT&E laboratory organization. The same measures can be applied across a diverse spectrum of RDT&E activities, providing DOD with a mechanism to evaluate performance of competing DOD RDT&E laboratory resources.

This remainder of this Chapter answers the research questions developed in the first Chapter, and indicates potential areas that require future research.

B. RESEARCH QUESTIONS

1. How do we measure capacity utilization and productivity of DON RDT&E facilities in terms useful for financial and resource allocation decision making?

Industry models and techniques provide guidelines for proper performance

measurement of RDT&E activity. Based on the objectives of the NAWCAD RDT&E organization and attributes of models studied, this thesis identified the CAM-I capacity model as a method of measuring and reporting capacity utilization for RDT&E laboratories. Revenue and full cost relationships were identified through return on operations, operating margin, and operating margin per square foot calculations as financial productivity measures of laboratory performance. Plotting the two dimensions of performance, capacity utilization and productivity, together on a performance comparison chart provides a financial management tool for strategic resource allocation decision-making.

2. **What are the plausible methods of measuring capacity utilization and productivity for RDT&E facilities?** Twelve separate capacity utilization models shown in Appendix A were reviewed as potential models for NAWCAD RDT&E laboratories. Laboratory equipment utilization was identified as an indicator of capacity utilization for individual laboratories. Equipment utilization data input into the CAM-I capacity model illustrated the model's ability to communicate capacity utilization information in terms useful for financial decision-making. Productivity measures were developed by using accounting concepts and ratio analysis procedures commonly found in industry. Revenue and cost relationships shown as a ratio in the return on operations index and as a dollar amount in the operating margin calculations are identified as plausible productivity measures for individual laboratories. These measures are closely related to the Navy Working Capital Fund account structure that governs NAWCAD RDT&E financial

operations. Additionally, the model and measures are designed to integrate with activity-based costing (ABC) systems and will be enhanced by the additional levels of accounting data provided by ABC.

3. **Can existing production capacity models be applied to non-production environments such as research laboratories?** The CAM-I capacity model was identified as the best fit for the unique RDT&E environment. The CAM-I model has been used in both production and service industries. Its flexibility in capturing and reporting different types of capacity information give credibility to its potential use in the RDT&E laboratory environment.

4. **Are there existing Research and Development benchmark performance measures in industry?** No standards of performance were found with direct application to the NAWCAD RDT&E laboratories. The Boeing Company was identified as a potential source for benchmark application, but lack of access to specific financial and operational performance information limited full evaluation.

5. **Can similar measures be applied to DON RDT&E laboratory facilities?** The potential exists for benchmark application of performance measures found in sources external to NAWCAD. Boeing, NASA, and the British Defence Research Agency were cited as organizations exhibiting RDT&E laboratory activity and organizational structure similar to that of NAWCAD. A review of techniques and methods used by these organizations provided multiple approaches to performance measurement of laboratory activity.

6. **Can dissimilar laboratories be classified into categories useful for financial performance comparisons?** NAWCAD Aircrew Systems (4.6) Level II laboratories were classified by competency and facility type to compare performance against category averages established for this research. Results indicate a relationship between facility type and ROOI. Classifying laboratories by facility type may provide management with better decision-making information when comparing financial performance of functionally dissimilar laboratories.

7. **Can a consensus approach to measuring capacity utilization and productivity be applicable to all RDT&E activities?** The CAM-I capacity model and productivity measures identified in this research are applicable to all RDT&E activities operating as NWCF accounts. Additionally, alternative measures of capacity utilization that may be developed in the future can be incorporated into the CAM-I capacity model to accommodate continued discovery in the study of RDT&E capacity utilization measurement.

C. SUGGESTIONS FOR FURTHER RESEARCH

Based on arguments and facts presented in this thesis, the following recommendations are offered to help the Naval Air Warfare Center Aircraft Division and the Department of the Navy obtain better decision-making information and performance from its limited RDT&E resources:

1. The CAM-I capacity model and productivity measures used in this thesis, applied to a larger sample of NAWCAD Level II and Level III laboratories, will provide NAWCAD RDT&E management with additional levels of detail and analysis from which evaluation of research results can be significantly enhanced. The results from this thesis were based on data collected from the nine Aircrew Systems (4.6) Level II laboratory groups. A larger sample of Level II laboratories and data collected for individual Level III laboratories are recommended to further investigate and validate the potential use of the measures described in this thesis.

2. Capacity utilization was determined in this research by an estimate of laboratory equipment utilization. Further observation and analysis of actual equipment utilization is recommended to substantiate the findings in this thesis. The time sheet example provided in Table 7.1 could be used as a data collection tool.

3. Further research is recommended to identify alternative methods of measuring capacity utilization. Equipment utilization was determined in this research to be one indicator of laboratory capacity utilization. Other viable measures may exist. For instance, laboratory personnel were considered one of the inputs to laboratory capacity. A measure of personnel utilization may be useful in determining overall laboratory capacity utilization. Obtaining accurate records of personnel activity within the laboratories may be difficult or impossible under the current accounting system. Implementation of management controls designed to report activity of key laboratory personnel might be required to provide the data necessary for detailed analysis.

4. A more detailed review of the capacity utilization metric and laboratory performance measures developed by Boeing may provide potential benchmark measures for NAWCAD and other DOD laboratories. In the absence of compatible industry RDT&E benchmark measures, NAWCAD should establish internal standards of performance for laboratory capacity utilization and productivity. Additional data are required to develop appropriate performance standards.

5. Categorizing laboratories by their operating characteristics, and comparing performance among similar types of laboratories, may provide a more relevant baseline of comparison. For example, laboratories primarily using large mechanical equipment in a high bay mechanical facility may exhibit cost and activity behavior significantly different than laboratories primarily using small technical equipment in a raised floor computer and electronics facility. Separate benchmarks of performance could be established for laboratories with similar characteristics. Three distinctive categories of laboratory facility type were used in this thesis to compare performance against specific category benchmarks for the NAWCAD Aircrew Systems (4.6) Level II laboratories. The results indicate a potential relationship between facility type and productivity. A larger sample of laboratory data is required to further explore this relationship and to determine if other performance relationships exist.

6. Integration with activity based costing systems will provide the level of detail necessary to accurately measure individual laboratory performance at the Level III organizational level. Coordination between the NAWCAD ABC initiatives and the

laboratory performance measurement research should enhance the implementation of future financial management control systems.

7. Further research is recommended to investigate and develop non-financial performance measures to complement the financial performance measures described in this thesis. A comprehensive performance evaluation of RDT&E laboratory activity should not be limited to capacity utilization and productivity measures. The intellectual capacity of researchers and scientists, value chain analysis, and identification of core competencies are a few examples of potential non-financial measures.

8. Identify core activities vital to mission and fleet support. Some laboratories may provide unique functions not available from other sources. Others perform functions required for direct fleet support that are considered indispensable. The capabilities of these laboratories cannot be reduced or eliminated without dramatically affecting overall mission readiness of the fleet. Specific criteria for evaluating laboratories as vital to mission readiness should be established. An official list of these core RDT&E laboratories could provide an additional layer of analysis when evaluating performance of individual laboratories.

9. Coordinate with other branches of the Armed Services and federal agencies to design and implement a consensus approach to measuring RDT&E laboratory financial performance. The results of this thesis and other relevant reviews may be used to initiate a joint research effort to provide DOD with standard metrics for determining individual laboratory performance. The CBMT is a service wide tool developed to

provide executive level visibility of full costs for DOD RDT&E activities. An extension of the CBMT model to the individual laboratory level may serve as a catalyst for development of service wide measures of individual laboratory capacity utilization and productivity.

APPENDIX A

COMPARISON OF CAPACITY COST MEASUREMENT MODELS

Model / Features	Baseline Capacity Measure Emphasized	Primary Focus of Model	Suggested Treatment of Idleness Costs	Other Programs Supported	Required I/S Capabilities	Data Requirements	Resources Required	Planning or Control?	Strong Tie of Financial and Operational Suggested?
Resource Effectiveness Model	Theoretical Capacity	Resource Utilization	Charge to Profit & Loss	Continuous Improvement TOC & ABC	Moderate	Moderate	Moderate	Planning	Yes
Capacity Utilization Model	Theoretical Capacity	Capacity Utilization	Charge to Profit & Loss	Continuous Improvement & ABC	Moderate	Moderate	Moderate	Both	Yes
Capacity Variance Model	Theoretical Capacity	Analysis of Performance	None Suggested	Continuous Improvement	Minimal	Low	Minimal	Control	Yes
CAM-I Capacity Model	Theoretical Capacity	Communication	Charge to Profit & Loss	Continuous Improvement & ABC	Sophisticated	High	Moderate to High	Both	Yes
CUBES Model	Theoretical Capacity	Process Utilization	None Suggested	Continuous Improvement & ABC	Sophisticated	High	Moderate to High	Both	Yes
Cost Containment Model	Implicit Theoretical Capacity	Total Cost/Activity	None Suggested	Continuous Improvement & ABC	Moderate	Low	Minimal	Planning	No
Gantt Idleness Charts	Practical Capacity	Efficiency	Charge to Profit & Loss	Continuous Improvement	Minimal	Moderate	Minimal	Control	No
Supplemental Rate Method	Practical Capacity	Supporting both internal & external reporting	Charge to Product	Continuous Improvement	Minimal	Low	Minimal	Control	Yes
Theory of Constraints Capacity Model	Practical (Marketable) Capacity	Throughput	None Suggested	Continuous Improvement	Minimal	Low	Minimal	Both	No
Normalized Costing Approach	Normal Capacity	Decision Analysis	Charge to Profit & Loss	Continuous Improvement & ABC	Moderate	High	Moderate to High	Both	No
ABC and Capacity Cost Management	Normal Capacity	Resource cost per activity	Charge to Profit & Loss	Continuous Improvement	Moderate	Moderate	Moderate	Planning	Yes
Integrated TOC-ABC Model	Various	Minimize marginal cost	None Suggested	Continuous Improvement & ABC	Moderate	Moderate	Minimal	Both	Yes

APPENDIX B

AIRCREW SYSTEMS (4.6) LEVEL II LABOARATORY QUESTIONNAIRE

Questionnaire

Please take a few minutes to complete the enclosed questionnaire and return to Don Harris by Friday, 20 March.

- Responses should be based on **ESTIMATES** of actual usage rates experienced in FY97.

- **Each Lab should be considered as one entity.**
  Exception: (If the functions, equipment, and physical space of the individual lab components are significantly different from one another, please complete a separate questionnaire for each entity.)

Lab Title ______________________________

Name of Respondent ______________________________

Phone # ____________________

E-mail ____________________

LAB DESCRIPTION

1. Lab Facility Physical Space Description

Select from the following list the option that **best** describes the physical space that the lab occupies:

_____ High Bay Mechanical (large equipment and storage labs)

_____ Computer and Electronics (raised floor labs)

_____ General Purpose Clean Lab

_____ Other (describe)____

2. Lab Function Type

Consider the total volume of work performed by the lab in FY97 and **estimate** the amount (%) of the total that was spent performing the following functions:

(Enter **0** if the listed function does not apply to the lab)

______% **Production** (Lab tasks consist of repetitive, defined tasks)

______% **Research and Development (R&D), Research Development Test and Evaluation (RDT&E)** (Lab tasks are not well defined, nor repetitive)

______% **Certification** (Lab is required to validate aircraft system prior to flight, flight clearance, or fleet use)

______% **In-Service** (Lab is used primarily to provide direct support to fleet to troubleshoot & correct problems)

______% **SSA** (Lab is a software support activity)

______% **Other** (Describe) ____

__100__% Total Work performed by the lab

3. Lab Equipment Type

Choose the option that **best** describes the type of equipment used in the lab:

_____ Large mechanical test device (single or multiple)

_____ Technical work bench areas (multiple work areas designed for tasks utilizing specific equipment or technology) i.e. *electronic test benches, simulation and modeling computers, video analysis equipment.*

_____ Non-Technical work bench areas (multiple variable use work areas designed for a variety of tasks not restricted to specific equipment or technology) i.e. *open lab benches for material handling, parts and inventory.*

_____ Other (Describe) ____

EQUIPMENT UTILIZATION
The following questions ask for responses about **utilization** of the Lab equipment identified in the previous section. The questions ask you to identify how the equipment is used during **normal working hours – 5 days/week, one 8-hr shift** – not including holidays or other legitimate non-work days.
Note: *If the equipment is used in excess of normal working hours on a Regular Basis, read Note 1 at the end of the questionnaire.*

Equipment use is divided into three categories; **Productive, Non-productive, and Idle**

Please provide the appropriate percentage of utilization for each category. The sum of the three categories should account for 100% of the equipment usage during normal working hours.

1. **Productive**

What percentage of *time* during normal working hours is the Lab Equipment used for the following activities?

______ **A.** Producing output directly tied to sponsor funded projects (revenue generating projects)
______ **B.** Producing output not tied directly to sponsor funded projects (work initiated to gain improved product quality or new product development but not linked to revenue)
______ **C.** Process development (work not associated with a specific product or revenue, but initiated to improve Lab processes, technology, and capability)

______**% Sub-total**

2. **Non-productive**

What percentage of *time* during normal working hours is the Lab Equipment used for the following activities?

______ **A.** Required preparation, set up and tear down **NOT** funded by project sponsors.
______ **B.** Scheduled and Unscheduled Maintenance
______ **C.** In Standby mode (The equipment has been set up and prepared for scheduled tasking but is not presently in use - delay time between set up and actual use)

______**% Sub-total**

3. **Idle**

What percentage of *time* during normal working hours is the Lab equipment **NOT** being used for the following reasons?

______ **A.** Restricted use of Lab equipment due to Contractual requirements, Legal requirements, or Management Policy (Strategic decision to protect excess capacity for mission critical contingency requirements)
______ **B.** Lack of Demand * Idle but Usable (Available for additional business, market opportunities)
______ **C.** Non-Marketable Product/Output * Idle but **NOT** Usable in its present condition (No market exists for Lab equipment capabilities; equipment may be outdated or requires additional investment or upgrade)

______**% Sub-total**

Keep in mind that:

- **The sum of percentages given in questions 1, 2, and 3 must equal 100%.**
- **The sum of percentages for parts A, B, and C of each category must equal the section sub-total.**

Note 1

If the Lab equipment is utilized in excess of normal working hours on a ***REGULAR BASIS****, limit your responses to include only* ***normal working hour*** *utilization estimates. In the space provided below, estimate the average number of* ***additional*** *hours of use per day and categorize the additional use of the equipment as either Productive or Non-productive.*

Average Number of Additional Hours per day:

Productive ________________________

Non-productive ________________________

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